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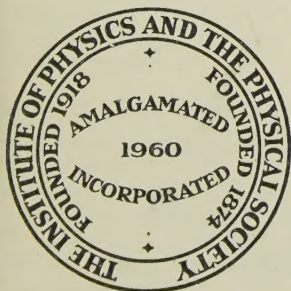
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Some aspects of research on thin solid films

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Abstract

The practical importance of the structure of thin films deposited in vacuo and of the relationship between film and substrate is illustrated by description of a number of thin-film devices. A brief history of research on thin films leads to a survey of some recent work on the creation, growth and structure of films examined by electron and field emission microscopy, and on the measurement of film-substrate binding energy.

Thin films in instruments

TEN years ago thin films would have been thought of mainly in the context of optics. Optical mirrors with vacuum-deposited reflecting surfaces were already well known, while interference filters, anti-reflection films and several other devices exploiting the controlled interference effects obtainable by vacuum deposition processes were becoming essential components of modern instruments. The construction of these thin-film optical elements is now normal industrial practice but, in addition, many new applications have been discovered for thin films, based on their electric, magnetic, photoelectric and thermoelectric properties. The description of new applications which follows will show why fundamental research on the structure of thin films has acquired great practical importance, especially in the instrument industry.

In the applications so far mentioned, the films will have been prepared by evaporation of the appropriate materials in high vacuum or possibly by sputtering. This article will be concerned solely with thin films produced by these processes.

In some of the newer applications the motive for the use of thin films is the necessity of reducing the size of electric and magnetic components. It is safe to say that electric components (resistors, potentiometers and capacitors) and suitable magnetic elements of 'microminiature' size absorb a major part of the research work now being carried out on thin films.

Electric circuit components. In the construction of electronic equipment on a microminiature scale, the solid-state diodes and transistors are fairly readily reduced to a small size without changing their normal construction, but resistors, inductors and capacitors of conventional form require a practical minimum size which is comparatively bulky. The aim of microminiaturization (Dummer 1959, Danko, Key and McNaul 1959) is to reduce all components to a practically negligible thickness, so that either single components or groups of components can be mounted on circular plates. The single component 'micromodules' are stacked, with connecting wires running from storey to storey, and the assembly is potted, giving a block of variable height on a base 0.31 in. $\times$ 0.31 in. The plates for complete unit assemblies (perhaps an amplifier stage or an oscillator)

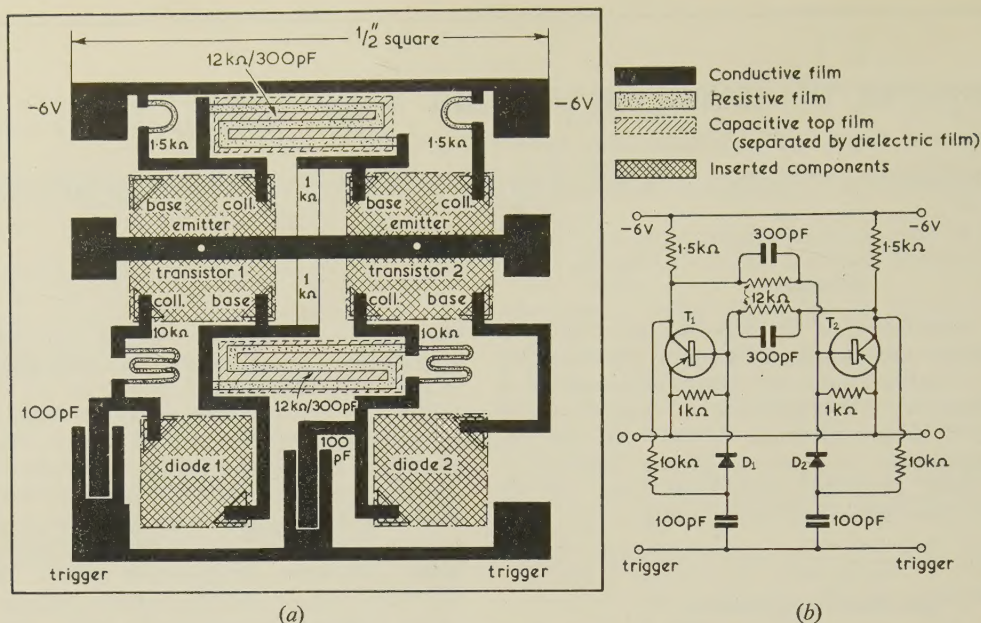
are larger, with a basic module of $\frac{1}{2}$ in. $\times$ $\frac{1}{2}$ in., and in this construction the components on each plate are connected by printed circuits (Fig. 1).

The only way to construct the very small passive elements is to make use of the methods of thin film deposition. In the case of capacitors, both the plates and the dielectric films may be deposited *in vacuo*, if necessary building up a stack of films to attain capacities of the order of $1 \mu\text{F}/\text{cm}^2$. Glass or ceramic dielectrics can be deposited in this way including, where operating temperatures allow, high permittivity materials such as barium titanate; metallic oxides such as silicon monoxide are also being tried. Alternative methods are to deposit metal on both sides of a cast film of synthetic resin or to deposit a metallic electrode on a ceramic base, oxidize the surface to form the inter-electrode dielectric and then deposit the counter-electrode. The electrode metals can be chosen to suit these various processes: for instance, tantalum can be deposited by sputtering and anodized to give a surface oxide with a dielectric constant of 25 (Berry and Sloan 1959); the counter-electrode would be aluminium or gold and would be put down by high-vacuum evaporation.

The problems in the preparation of thin-film capacitors are chiefly those of finding dielectric materials which will give a rather thick film of stable structure and good electric properties—high dielectric constant and high breakdown voltage. With such thin dielectrics the breakdown voltage is of high importance. Maximum working voltages are in the region of 10–50 v, so that for a dielectric thickness of 1μ an electric strength up to 5×10^5 v/cm is called for.

Thin-film resistors (Dummer 1959) present a rather more difficult set of problems, since the resistance film must be electrically stable to a high degree, wear-resisting if a wiping contact is involved (though in a rheostat contact can be made through mercury), and capable of being accurately adjusted to predetermined values of resistance over a very wide range. Very thin films tend to be very unstable, so in order to reach high resistance values while still maintaining a thickness not less than about 100 Å, a long path has to be achieved within the available area. The film is therefore patterned (as a zig-zag or a double spiral), the pattern being etched in the film through a mask produced photographically in light-sensitized glue. (This combination of photo-etching and thin-film deposition is, incidentally, of great value in many other applications where fine gratitudes and other intricate patterns are wanted.) If the metal is one that is not easily etched, it is possible to produce a pattern by photographing a negative replica on the substrate in sensitized glue, depositing the metal over all and then applying nitric acid to dissolve the glue; the metal overlaying the glue pattern is carried away, leaving a metallized 'image' of the parts of the pattern that were clear. An improvement on this method is to substitute a vacuum-deposited copper pattern for the glue pattern.

With the photo-etching process it is possible to make



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Fig. 1. Proposed layout (a) and theoretical circuit diagram (b) of binary-counter stage in flat-plate form.

extremely fine patterns and so to cover the necessary range of microminiature resistances. The conventional cylindrical resistor may have a metallized film deposited outside or inside a hollow cylinder and divided into a helix by spiral cuts.

The metals used for thin-film resistors are generally alloys of high resistivity and low temperature coefficient of resistance. A nickel-chromium alloy is commonly used, and so are palladium-gold and other noble-metal alloys. Deposition of these alloys by volatilization is, rather surprisingly, possible in spite of the difference in vapour pressures of the constituents, though, of course, a fast rate of evaporation generally results in less disturbance of the constitution than would a slow distillation.

Microcircuitry. The reproduction of printed circuits by plating is rather too clumsy a method to match the microminiature components, and there is a considerable advantage in applying identical principles for making the circuit elements and their connections. Experimental methods have already been evolved for making up transistor circuits on small boards in which the resistors, the basal electrodes of the capacitors, and the connections are all of tantalum, deposited through copper masks. The capacitors are completed in two further operations, the rest of the circuit being masked with wax. A typical layout contains twenty-four resistors with a highest value of 121 kΩ and nine capacitors of $0.01 \mu\text{F}$ within an area 2 in. $\times$ 2 in. Although the transistors themselves (three in the example quoted) are very small, they are, of course, not 'to scale', and it seems likely that sooner or later the task of manufacturing transistors or the equivalent active element by thin-film techniques will have to be attempted.

Magnetic films. A 'square-loop' magnetic material (that is, a material having a B-H curve which is nearly square in shape) can be adjusted to either of two stable states of magnetization; this bistable property is used in two ways.

In the first, the function is that of a fast switch which may be set by a small pulse and is then capable of either passing or blocking an energy pulse. The bistable material forms the

core of an elementary transformer with an additional winding for 'setting' the direction of magnetization of the core.

In the second application, the two stable states represent digits in a binary digital system and the device becomes an element of a mathematical computer, acting as a core in an elementary transformer having 'read' and 'cancel' windings.

A very convenient and effective way of achieving square-loop characteristic is to deposit a magnetic material as a thin film on a heated substrate in the presence of a magnetic field parallel to the plane of the substrate (Hart 1955). The magnetic field defines the direction of magnetization in the film, and the square-loop characteristic appears when the 'driving' field is parallel to this direction. (Other methods of ensuring a uniaxial anisotropy are to deposit at a high angle of incidence or to strain the film by bending the substrate.) Square-loop magnetic films are highly suitable for the applications already described, since by means of a masked substrate, they can be prepared as a compact array of small cores. The time taken for electron spin orientation to reverse direction on applying a reversing field is of the order of $1 \mu\text{s}$ or less: as a storage element, the magnetic film therefore qualifies as a fast switch.

Several schemes for logical and memory components, making use of the transition region in thin-film superconductors, are in the experimental stage. The principle on which these devices are based is that in the region near the critical temperature (about 4°K), transition from superconducting to the normal state can be brought about by imposing the magnetic field of a current-carrying conductor (Young 1959). In its simplest form such a device is known as a cryotron. The thin-film superconductor has the advantage that, in spite of very small dimensions, its resistance in the normal state is relatively high. The dimensions are also favourable for a short response time: the thin-film cryotron has a time constant of the order of microseconds. Other thin-film bistable elements, such as the Crowe cell (Crowe 1957), are based on the reversal

sistent currents in superconducting films, and these are better than the cryotron; they can be switched in 50 m μ s.

The metals having the most convenient critical temperatures for cryotrons are tantalum and tin; the permanently superconducting connections are made in lead.

Photon and thermal infra-red detectors. Infra-red detectors have recently gone through a period of rapid development. The photon-activated lead sulphide, selenide, and telluride photoconductive detectors are prepared by a carefully controlled series of evaporations *in vacuo* in the presence of a trace of oxygen. The sensitivity of the photoconductive material is evidently strongly dependent on the precise way in which these evaporations and condensations proceed and, in fact, it is difficult to reproduce sensitivity in the production of detector cells by this method, or even to deposit a photoconductive surface which is uniform in sensitivity over its whole area. The advent of photosensitive semiconductors, such as germanium, silicon, and indium antimonide in a very high state of purity (and hence reproducibility), and the raising of the upper wavelength limit of absorption in germanium by the controlled addition of impurity centres, has put thin-film detectors in a precarious position as far as measurement in the region above 3.5 μ is concerned.

Some of the photoconductive detectors which are sensitive to visible light, namely the cadmium sulphide and selenide cells, are also made by vacuum deposition; their sensitivity depends very critically on the amount of oxygen in the residual atmosphere (Schwarz 1948).

The quantum-activated photocells of recent development have by no means made the thermal detectors obsolete; though the range of impurity-doped semiconductor photoconductors has been extended almost to the microwave region, thermal detectors are still the most convenient type for measuring radiation of wavelengths above 10 μ . Their comparatively low speed of response is, however, a disadvantage when chopped radiation or rapid changes in radiant flux have to be recorded. To meet the requirement for higher speeds of response, bolometers of very low heat capacity are now constructed by depositing gold films on thin organic films and blackening the surface with a thin black deposited by evaporation in a low pressure of oxygen (Archbold 1957). Thermocouples can be made in a similar way by evaporating metals such as antimony and bismuth (or even a pair of semiconductors) through masks onto a thin cast film of nitrocellulose or Formvar, so that the strips are deposited end-to-end and overlapping to the extent of half a millimetre or so. For high ambient temperatures, or in exposure to intense thermal radiation, the plastic substrate sets a limit to thermocouples of this construction, but self-supporting inorganic substrate films can now be prepared in a well-controlled way and will replace the cast films (Bennett 1959).

The particular applications of thin films which have been described were chosen to represent some of the more important advances in instrumentation in which thin films are involved. There are many other interesting thin-film devices which can only be touched on here. The many types of image receivers, image converters and light amplifiers, in which thin films are called upon to perform a variety of functions associated with the formation, storage and development of the electrical charge, form a subject of which the progress has been well described (McGee 1957). A certain amount of very interesting work is, nevertheless, still not suitable for publication.

In the field of classical optics, probably the most important recent advance is the commercial production of the two-layer

anti-reflection film. This is much more efficient in reducing reflection at the surface of normal glasses than is the single-layer film of magnesium fluoride or cryolite. Instead of depending on the phase retardations due to two quarter-wave layers (which produce a rather narrow trough in the spectral reflectivity curve), the latest combination consists of a very thin inner 'phase-shifting' layer of high reflectivity and an outer quarter-wave film of magnesium fluoride (Osterberg, Kashdan and Pride 1952, Holland and Putner 1959). The production of the two-layer film is an exercise in the accurate control of film thickness and in the attainment of durability in the layer of high refractive index.

Interference filters are gradually being extended in their range of operation, both towards the ultra-violet and the infra-red regions, and methods of designing and constructing them have advanced considerably; nevertheless, the incursion of thin films into the field of optical instruments has not maintained the impetus which was gained in the 1940's, largely because most of the pioneer work was done during that period.

The process of reactive sputtering provides a very useful method for depositing metallic oxide films, which are difficult to deposit by the thermal method because they tend to dissociate (Holland and Siddall 1953). A bismuth oxide film made in this way has a refractive index of about 2.45 and is useful as an optical beam-splitter, but it also has the peculiar property (discussed later in this article) of so controlling the structure of a superimposed gold film that the gold has an exceptionally low resistivity (about 10 Ω /square for a film of 80% transmissivity). These unusual gold films have two industrial uses, as transparent conducting coatings for carrying a heating current on windows (Holland 1956) and as heat-reflecting filters (Holland and Siddall 1958).

This is far from being an exhaustive account of the many ways in which thin films find useful applications, but the applications described will show why research into the formation and properties of thin films is of immediate interest and importance.

Historical note on thin-film research

The earliest references to thin films prepared by evaporation or sputtering are in connection with measurements of the optical properties of metals; the semi-transparent specimens which could be prepared by these processes made possible (so it was thought) the determination of absorption factor and refractive index. (We now know that these values cannot be assumed to be those of the metal in massive form.)

As a laboratory art and in small-scale industrial applications the deposition of metal films by sputtering had been practised for many years, but in the late 1930's a great expansion in these film applications began. This was due to advances in vacuum engineering which raised thin-film deposition to something approaching a reliable industrial process. The routine for aluminizing glass as it is used today was worked out by Strong in 1936, and in America and Germany anti-reflection coating of optical components was commercial practice before 1939.

The Second World War stimulated an urgent demand for aluminized mirrors, silvered Perspex prisms, neutral filters, beam-splitters and anti-reflection films, all for the many optical instruments in wartime use. This great volume of thin-film application was only achieved after many kinds of fault and failure had been encountered and overcome by means entirely empirical. Some effects, such as the tendency of cryolite films to change their interference colour in an

atmosphere of high humidity only when the humidity was also high at the time of deposition, have never been satisfactorily explained.

The technology of thin-film deposition processes and an acquaintance with the properties of thin films were thus gradually built up, very largely on the basis of trial and error. This is not to say that scientific investigation of the properties of thin films was neglected. Even during the war a little work was done on the structure of films and, as the urgent necessity to maintain wartime output at any cost eased off, experimentation became more systematic. Many research workers in this field were attracted by the problem of measuring the optical properties of films and accounting for these properties in terms of a postulated structure. This work firmly established the fact that the structure is, generally speaking, an aggregation of sub-microscopic particles. The idea itself was not new: it had been discussed by Maxwell-Garnett in 1904. It must be admitted that a good deal of the research stimulated by this aspect of the subject has run into a blind alley, since it contributes nothing to the problem of what factors determine film structure.

Interest in the electrical properties of thin films was encouraged by the realization that they offered the opportunity of verifying theories of electrical conduction, thermoelectricity and various other effects due to the conduction electrons in metals. H. Mayer (1959), a strong advocate of the use of thin films in this branch of physics, has pointed out, however, that only if the utmost care is taken to maintain the right conditions of deposition, including ultra-high vacua, will the films have a purity or a structure comparable with that of the bulk metal. The same limitations apply to work on the magnetic properties of films, and here again recent work with films prepared in ultra-high vacua has given results in which there is no reflection of any anomalous structure.

The systematic investigation of epitaxy, the power of crystalline substrates to orientate the lattice of superimposed films of similar or dissimilar crystallographic structure, was at first undertaken to study the validity of theories such as that of Frank and van der Meer, concerning the extent to which misfit between substrate and film lattice is permissible for epitaxial growth. It was soon discovered that there is, in general, no limit to the degree of permissible misfit. Although this is in itself a negative result, the research directed attention to the importance of nucleation in the earliest stages of film growth and to the possibility of examining this phenomenon by means of electron diffraction and electron microscopy. It also led to a method for preparing thin-film single crystals (Pashley 1959, Bassett and Pashley 1959). One of the important discoveries at this stage was that the first few atoms condensed on a substrate aggregate into islands, which can be either monomolecular layers or three-dimensional arrays. An early observation by Finch and Quarrell suggested that the inter-atomic spacing of the atomic layer in contact with a crystalline substrate might be distorted to fit that of the substrate, but this has since been disproved. [A review of the subject of epitaxy is given by Pashley (1956).]

In this historical sketch of experimentation on thin films, we are now approaching the present time. Thus far, the situation may be summed up in this way: interest in the practical problems of film deposition led to an examination of the physical properties of the films—optical constants, hardness, adhesion, epitaxy, electrical and magnetic properties. These properties all vary with the structure of the film, and when this was fully appreciated there began a movement away from empirical experimentation and towards a more fundamental understanding of the process of film

deposition and growth. This movement has, in effect, joined up with the thin stream of academic research which, withdrawing much attention, had run its course since the time of Faraday. At the same time, the pressure on development laboratories for thin-film devices such as micromodules and magnetic computer stores encourages the technological approach: hence the method of 'deposit and test' has to be pursued with intensified zeal.

Research on condensation and nucleation

The outstanding features of thin films are that most of their properties are structure-sensitive, and that the structure depends on the conditions under which the deposit is formed and on the relationship between the film and the substrate. The data published in accounts of measurements on films are often of little value because of the indeterminate nature of these controlling factors. The sort of information on conditions of deposition which is sometimes thought to be adequate is that the specimens were very kindly supplied by the laboratory next door.

The starting point of the fundamental research on thin films may be taken as the independent observations of Knudsen (1915) and Wood (1915, 1916), that when mercury or cadmium is evaporated at normal rates in a high vacuum it does not condense at all on a substrate above a certain critical temperature, even though the degree of supersaturation is very high. At first it was thought that this effect was one of diffuse elastic reflection, but in Langmuir's view (1916) reflection in this sense could only occur in very rare cases: he suggested that the incident atom would be captured by the surface and retained for a time until a chance event released it again. There would be a rapid variation of the critical temperature with the vapour density. This hypothesis was taken a stage further by Frenkel (1922) who showed that the average life of an adsorbed atom might be determined by the statistical chance that it might gain enough thermal energy from the substrate lattice to re-evaporate; further, he showed that if the adsorbed atom is free to move on the surface it may unite with another adsorbed atom, and that the life of the combined atoms would be longer than that of the separate atoms. (The mobility of condensed atoms or molecules was by this time well known; Volmer (1921) having been the first to prove it experimentally.) Frenkel's theory is based on certain restrictive assumptions but it has been generalized (Mayer 1955). From these considerations arose the concept of nucleation as a fundamental process in the formation of solid films.

The process of nucleation has been approached in a rather different way by Pound, Simnad and Yang (1954). They adopted the same basic idea that incident atoms are adsorbed and are mobile on the substrate, and either evaporate again or form stable nuclei by chance collisions with other atoms. In this treatment the condition for the formation of a stable nucleus at a given temperature is derived from a consideration of the changes in free energy as the atoms condense, migrate and form a critical cap-shaped nucleus (a critical nucleus is one which is just large enough to be stable).

It follows from theories such as those of Frenkel, Pound and others, that for a given condensate-substrate combination there should be a relationship between the vapour density of the condensing metal beam and a 'critical' temperature above which condensation will not occur. For instance Frenkel's theory relates the critical temperature T_c to the beam density ν by the equation

$$\nu = 4\sigma_0\tau_0 \exp(u_0 + \Delta u)/kT_c$$

where σ_0 = effective atomic diameter, τ_0 = assumed period of vibration of condensed atom, u_0 = energy of adsorption per atom, Δu = energy of cohesion per atom, and k = Boltzmann's constant. Pound's equation is similar in general form. Cockcroft (1928) and many others [reviewed by Meyer (1955)], have found that a critical temperature does exist, and that the critical vapour density is an exponential function of $1/T_c$.

Devienne (1952) has pointed out, however, that when the substrate temperature is just below the critical temperature at a given beam density, the rate of film growth will be very low. The experimental determination of the critical temperature or beam density thus tends to depend on the sensitivity of the method of detecting the onset of condensation. He therefore carried out measurements with radioactive antimony and cadmium, detecting the presence of a condensed film with a Geiger counter. For cadmium on a substrate at 300°K he found a critical vapour density of $5 \times 10^{15} \text{ atoms cm}^{-1} \text{ s}^{-1}$, to be compared with the value $5 \times 10^{18} \text{ atoms cm}^{-1} \text{ s}^{-1}$ given by Cockcroft, who used a visual method for detecting the condensed film.

The difficulty of observing the critical condition is greatly increased in the case of a substance having a high critical temperature for beams of normal vapour densities. When the substrate temperature is low enough for practicable experimentation, the critical vapour density may be so low that,

for densities not much higher than the critical value, an inordinately long period must elapse before a detectable film is condensed.

In spite of these experimental difficulties, there is now sufficient evidence to support the idea that the anomalous structure of thin films originates in the formation of aggregates upon nuclei in the earliest stage of deposition, rather than in a re-arrangement of the structure at a later stage. A study of the phenomenon of nucleation under various conditions of deposition and on substrates of differing nature (amorphous, crystalline, atomically rough or smooth) is therefore essential to an understanding of the physical properties of films. For this reason there is at present a concentration of the powerful techniques of electron microscopy and field emission microscopy on the observation of the formation and early growth of aggregates.

Before looking at some of the latest results, it is interesting to note that in 1935 Andrade and Martindale drew attention to what is now called the decoration of submicroscopic surface irregularities on glass by nuclei of sputtered silver and gold. This clearly showed the high mobility of atoms on surfaces at temperatures far below the melting point of the deposit, and the aggregation of these mobile particles. Recently Bassett (1958) has published electron micrographs illustrating the decoration of monatomic steps on a rock salt cleavage face by gold nuclei (Fig. 2). Where sites of low



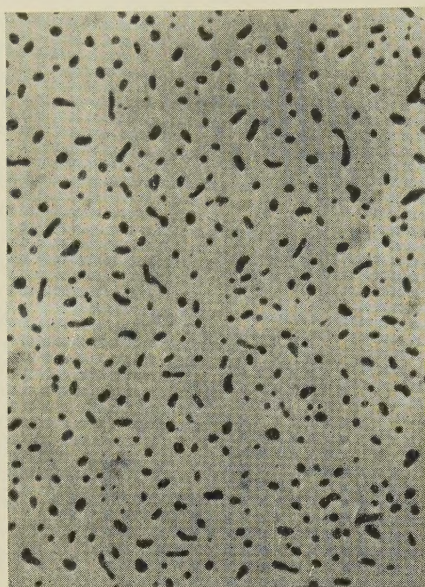
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Fig. 2. Decoration by gold nuclei of steps formed on cleavage face of rock salt crystal by heating the crystal at 250°C for 1 h ($\times 20,000$). (Bassett 1958.)

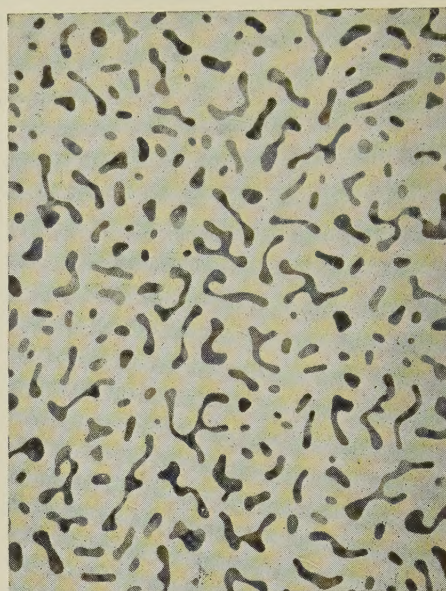
potential energy (such as submicroscopic cracks, atomic steps or corner sites on crystalline substrates) are not frequent, nucleation can apparently take place at random.

Mayer (1959) has shown that it is possible to prepare very

such films data have been obtained which confirm the theory of mean free path effects, such as the dependence of resistivity and temperature coefficient of resistivity on film thickness. Ohm's law was found to be obeyed for films



(a)



(b)



(c)



(d)

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Fig. 3. Successive stages in the growth of a gold film deposited on a (111) monocrystalline film of silver formed epitaxially on a cleavage surface of mica. The equivalent film thickness of the deposit increases from about 10 Å in Fig. 3(a) to about 50 Å in Fig. 3(d) ($\times 80000$). (Bassett and Pashley 1959.)

thin films (150 Å thick) of alkali metals which have a structure identical with that of the massive metal, modified only by an abnormally high dislocation density. His method is to inhibit the growth of aggregates by providing a substrate which is smooth on an atomic scale, and depositing a film of very pure metal under ultra-high vacuum conditions (10^{-9} torr) on a substrate cooled to prevent migration. With

thin as three or four monatomic layers. A clear picture of the microstructure of single crystal films, including the existence of dislocations within aggregates, can be shown by the electron microscope, using the diffraction contrast moiré fringe techniques. [A review of the application of these methods is given by Bassett, Menter and Pashley (1959).] The dislocation density in gold films deposited on (111)

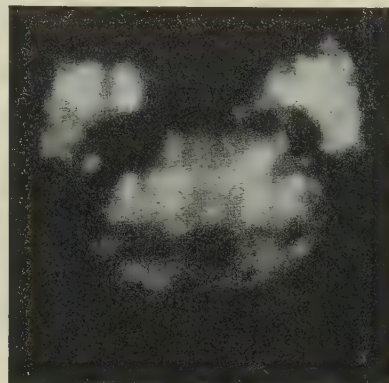
surfaces of orientated monocrystal silver films grown on etched mica is of the order of 10^{10} per cm^2 (Bassett and Ashley 1959).

The high resolving power of modern electron microscopes, coupled with the refinement of techniques such as those just mentioned, enables the deposition, growth and running together of nuclei to be observed stage by stage with static objects—the process must necessarily be arrested for

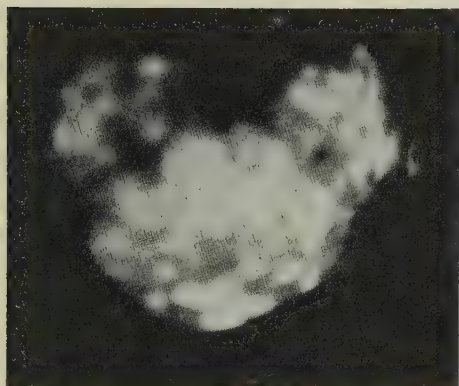
appearance of any aggregates. At high beam densities, aggregates were formed at an early stage. The behaviour at low beam density is at variance with the idea that the lifetime of single condensed atoms is very short. The difference between this particular set of experiments and all preceding work (which, as has been seen, confirmed that idea) is that in Moazed and Pound's microscope the substrate was heated to a temperature of 3000°K in a vacuum of 10^{-10} torr just



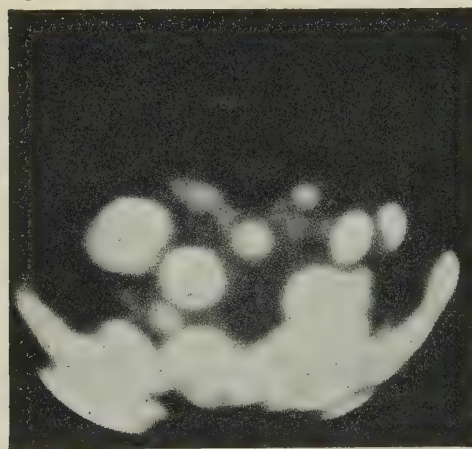
(a) Clean tungsten after flashing in a vacuum to a high temperature.



(b) $5\frac{1}{2}$ min after flashing. The bright spots are due to emission from individual silver atoms.



(c) $10\frac{1}{2}$ min after flashing. Larger bright areas indicate onset of nucleation.



(d) At a much later time. Nuclei have grown considerably at the expense of single atoms.

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Fig. 4. Field emission micrographs of adsorption and nucleation of silver evaporated on to tungsten ($\times 200\,000$). (Moazed and Pound 1959.)

observation (Fig. 3). In the field emission microscope, on the other hand, the process can be observed without a break in time, moreover, the activity of an individual atom is revealed. In this way, Moazed and Pound (1959) have observed the adsorption, migration and aggregation of silver on tungsten and molybdenum, as well as the adsorption and desorption of residual gases (Figs. 4 and 5).

Perhaps the most interesting feature of this field emission microscope study is that, under the prevailing conditions and at a low beam density, silver atoms were adsorbed in increasing numbers over a period of several hours without the

appearance of any aggregates. At high beam densities, aggregates were formed at an early stage. Under these conditions the binding energy of an isolated adsorbed atom is likely to be comparable with, or to exceed, the binding energy of an atom pair forming a nucleus, whereas nucleation theories, such as those of Frenkel, involving a metastable state apply only when the adsorption energy is comparatively low. Moazed and Pound modify Pound, Simnad and Yang's treatment of nucleation to take account of the new conditions.

There is, nevertheless, some quite striking evidence in these experiments to support established ideas. In particular,

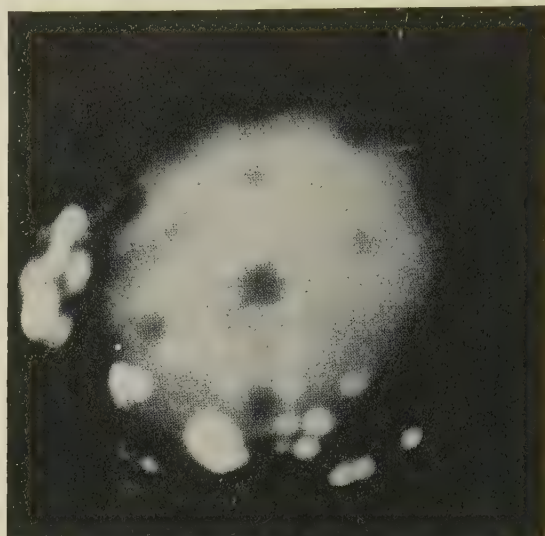
nucleation is seen to occur much more readily on areas of the single tungsten crystal which contain many steps and kink sites, than on the relatively smooth crystal planes. It is also shown that, even at a temperature as low as 200°K ,

atoms and their substrates. To understand this mechanism it is necessary to be able to measure the binding energy; at least three methods have recently been tried.

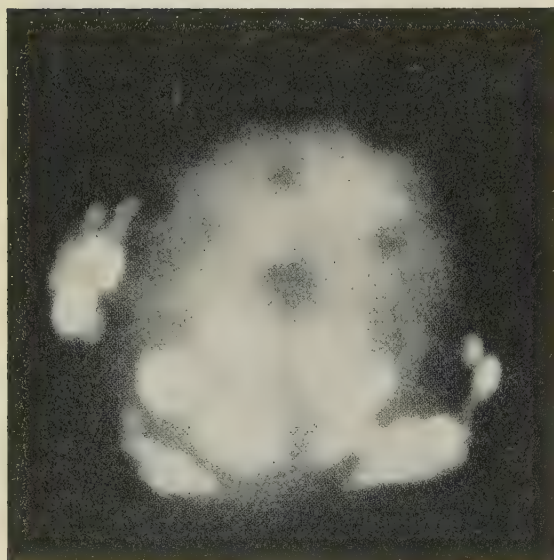
Eqn (1) suggests that the critical temperature method



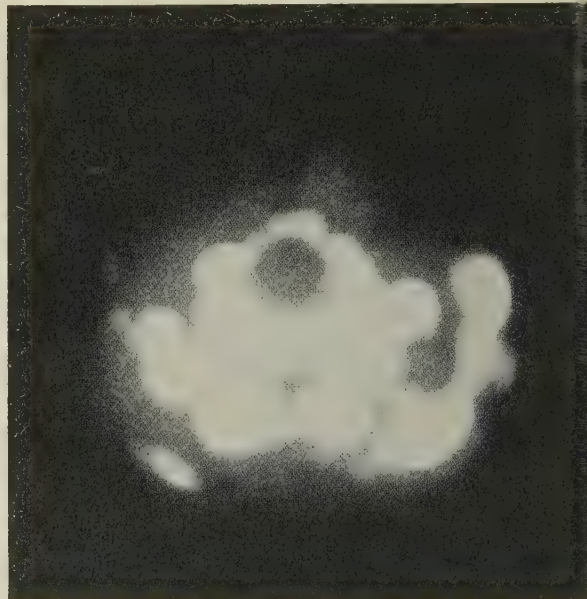
(a) Clean tungsten after flash.



(b) $\frac{1}{2}$ min after onset of nucleation (note early nucleation on left-hand side, occurring on tantalum lead to tungsten tip)



(c) $1\frac{1}{2}$ min after onset of nucleation.



(d) 35 min after onset of nucleation.

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Fig. 5. Micrographs taken as in Fig. 4 but with higher silver beam flux ($\times 100000$).
(Moazed and Pound 1959.)

the condensed silver atoms are highly mobile in certain preferred crystalline directions.

Adhesion of films to substrates

A subject on which very little fundamental research has been done is the *mechanism* of adhesion between condensed

atoms and their substrates. To understand this mechanism it is necessary to be able to measure the binding energy, provided that Δu , the cohesive energy of an adsorbed doublet, can be calculated. Rhodin (1949) has applied this method with aluminium on various substrates, plotting $\log p$ (vapour pressure) against $1/T_c$ and obtaining $(u_0 + \Delta u)$ for each substrate from the slope of the corresponding straight line. Rhodin found that the bond between aluminium

is negligible compared with the strength of the aluminium lattice, and that among the other substrates, it gave the highest binding energy at 20–22 kcal/mol.

Benjamin and Weaver (1959) have repeated the experiment with aluminium, silver and cadmium on glass, and with aluminium and silver on sodium chloride and potassium cyanide. They preferred to calculate the adhesive energy on a theoretical basis, and to examine the values of the cohesive energy of the metal (Δu) by subtracting u_0 from the experimental values of total condensation energy. The values of condensation energy for aluminium do not agree with Rhodin's measurements, but the value for cadmium on glass agrees well with that given by Estermann.

The remarkable feature of Benjamin and Weaver's results is that the theoretical adhesive energy which they have calculated is considerably greater than the experimental value of the cohesive energy. This is contrary to what would be expected in the case of a metallic film on a dielectric substrate. The equation (1), which Benjamin and Weaver use, is a simplified form based on the assumption that the cohesive energy is much greater than the adhesive energy.

These methods suffer from the practical difficulty of determining the critical condition, as has already been pointed out.

In fact, Bennett (private communication) has calculated that for silver condensing on glass at 192°C the critical beam density is 3×10^{11} atoms $\text{cm}^{-2} \text{s}^{-1}$, and that at this rate an electrically conducting film would only be formed in 100 hours. A comparable time would be required for aluminium condensing on mica at 560°C.

It seems to be generally assumed that in the ordinary run of experiments in demountable vacuum systems operating at 10^{-4} – 10^{-5} torr the binding forces are of the nature of 'van der Waals' forces in contradistinction to forces of a chemical nature. In special cases there is no doubt that a more intimate bond is established: the field emission microscope experiments are a case in point. Nevertheless, the adhesion of films on substrates such as glass and ceramics is of great practical importance, and there is an urgent need for a full understanding of the difference in 'adhesion' between the 'coherent' metals, rhodium, chromium, iron and aluminium, and the 'soft' metals, such as gold and silver, when the metals are deposited in the normal way. The inverted commas are used here because the fact that a film on glass can be scratched easily or with difficulty does not necessarily indicate a lesser or greater binding force. Other factors such as surface roughness complicate the issue, and a distinction must be drawn between resistance to abrasion and binding energy. The interesting question is whether chemical bonds can ever be formed in 'normal' evaporation processes, either directly between the evaporant and the substrate or (in the case of metals) through an intermediate film which may be an oxide formed in the vapour state. Metal oxides deposited as interlayers of a few hundred Å or more in thickness are known to have an important part in increasing the abrasion resistance of metal films (British Patent No. 605, 871 (1945)).

An attempt has been made by Benjamin and Weaver (1959) to convert a 'scratch test' into a quantitative method for measuring binding energy. The action of a needle point dragged across a metal-coated surface is analysed and it is concluded that the shearing of the adhesive bonds (resulting in a clear scratch) is a consequence of the plastic deformation of the substrate. On this basis a relationship is derived between the shear stress, the indentation hardness of the substrate, and the minimum vertical load on the needle necessary to make a clear scratch in the film. The binding

energy is calculated from the critical shear stress on the assumptions that shearing the film/substrate bonds is equivalent to sliding each film atom from one equilibrium position on the substrate to the neighbouring one over a potential barrier, and that the height of the potential barrier is a measure of the binding energy. While this research goes some way towards putting the scratch method on a scientific basis, it cannot be said that the agreement between the results so obtained and others quoted by the authors is yet close enough to prove the method. The fact that the critical loads for aluminium and gold films freshly deposited on glass under normal conditions are apparently identical does not seem to be in accord with common experience of the relative scratch resistance of these films.

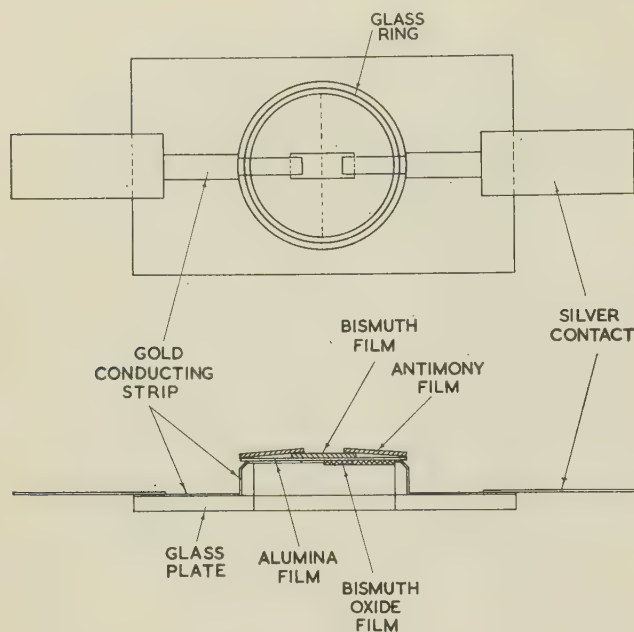
A very striking effect associated with certain oxide interlayers was discovered by Gilham and Preston (1952) and further investigated by Ennos (1957) and by Minn and Offret (1956). Gold deposited on glass by sputtering or evaporation normally has an aggregated structure, resulting in a film which transmits light of a greenish-blue colour, but if the glass is first coated with a thin film of bismuth oxide by reactive sputtering, the gold film deposited on the coated glass is a pale yellow in transmission. Furthermore, evidence from the electron microscope and from measurements of resistivity is that the film has a laminar structure and is a better conductor than a normal gold film. The gold film on bismuth oxide is quite strongly resistant to abrasion, whereas a gold film on uncoated glass is always quite 'soft'. The technical uses of this film have already been mentioned. A few other oxides, such as those of iron and lead, have a similar effect (Ennos 1957).

If the difference in structure between these two forms of gold could be explained, we should gain an insight into the mechanism of film formation which would considerably facilitate control of the structure-sensitive properties of films in general. One possible explanation is that free bismuth atoms or ions, the presence of which is suspected in freshly deposited bismuth oxide films (March 1959), act as capture sites for the condensing gold atoms, their surface density being sufficient to prevent the formation of large aggregates by the otherwise mobile gold atoms. A bismuth oxide film which is several days old is no longer active.

The exchanges of energy between the condensing gold and its substrate, in the case of gold on bismuth oxide and gold on a normal substrate, have been compared by Bennett (1959) using a new method developed by the British Scientific Instrument Research Association for measuring the very small differences in heat energy released at the two surfaces. The substrate in these experiments is a self-supporting film of aluminium oxide 500 Å thick (on which deposited gold behaves as it does on glass) (Fig. 6). One half of the substrate is coated with bismuth oxide. A differential antimony-bismuth thin-film thermocouple is deposited on the back of the substrate, so that the two junctions register differences in temperature between the substrates. The very low heat capacity of this assembly results in an output of 4×10^{-8} v for an energy release of $1 \text{ erg s}^{-1} \text{ cm}^{-2}$.

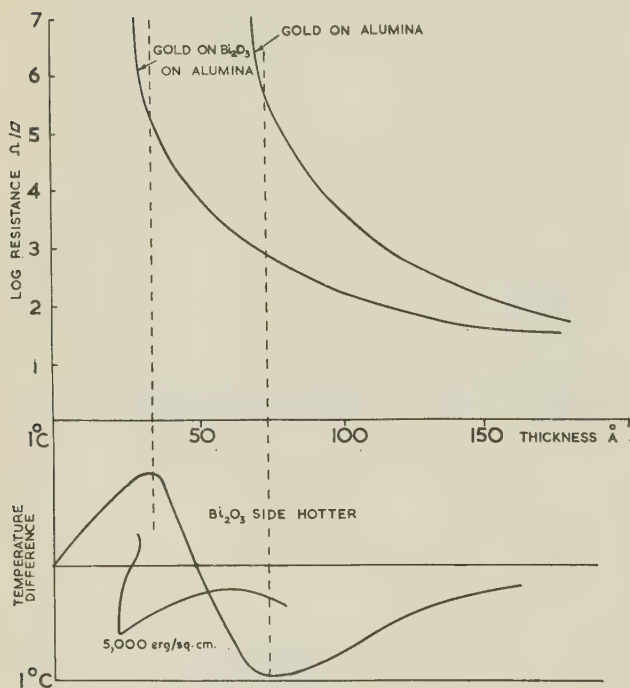
By evaporating gold on to the two substrates, Bennett was able to show that the quantities of heat energy per unit area liberated in the early stages of film growth were equal (5000 erg/cm²) for the two substrates, but that the release occurred sooner on the bismuth oxide than on the bare aluminium oxide (Fig. 7). Moreover, simultaneous measurements of film resistance indicated that the energy was in both cases released at about the stage when the growing film first became conducting—at a thickness of 40 Å for gold on

bismuth oxide and at 70 Å for gold on aluminium oxide. The amount of energy released agrees in magnitude with the decrease in surface energy when gold nuclei have grown to



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Fig. 6. Thin-film substrate with thin-film differential thermocouple for studies of adsorption energy of vacuum-deposited films. (Bennett 1959.)



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Fig. 7. Resistance/thickness and differential temperature/thickness curves for gold on alumina and gold on bismuth oxide substrates. (Bennett 1959.)

such a size that they unite to form a continuous layer. A very interesting negative result of Bennett's experiments is that, although the method is sensitive enough to detect energy differences of the order of 1 kcal/mol. in the binding energy of a monatomic layer of gold on the two substrates, no difference was detected during deposition of the first atomic layers. There is thus no evidence in these experiments of a significant difference in the nature of the forces of adhesion between the gold and the two differing substrates, although the structure and 'hardness' of the two gold films are different.

It seems probable from the accumulating evidence that the structure of very thin vacuum-deposited films depends, to a large extent, on the mobility of the condensed particles, and that this mobility is controlled by the spacing of centres of nucleation or, in the case of very clean substrates, by potential barriers due to the atomic structure of the substrate surface.

The abnormal structure of thicker films deposited under normal conditions is, however, not wholly determined by that of the first few layers. As Bassett, Menter and Pashley (1959) point out, inclusions of foreign gas molecules are likely to occur, and each successive atomic layer is probably deposited before the preceding layer has had time to attain thermal equilibrium. Refractive index measurements often give abnormally low values, indicating an aggregated structure. Moreover, condensed films are in some cases highly stressed (Murbach and Wilman 1953, Story and Hoffman 1957), so much so that the stresses may overcome the adhesive forces and cause the film to break up. Even the ordered structure of epitaxial films grown on single crystal substrates is lost at distances from the substrate exceeding a few atomic layers.

It is evident that the process of solidification by condensation from a molecular beam differs from crystallization from the molten state in some important aspects. The growth of the film in thickness deserves as intensive a study as is now being devoted to the initial stages of growth. The process of aggregation as a result of surface mobility may, perhaps, be found to be taking place continuously as the film grows. Certainly thick metal films can develop very large aggregates. Aluminium films develop the milky appearance characteristic of this condition when the vapour beam is incident at a large angle (Holland 1956) or on a hot glass substrate.

No doubt the technique of film deposition on ultra-clean surfaces in ultra-high vacua, of the order of 10^{-9} torr or less, will come into more common use in the field of research, thus bringing under control one very important variable, namely the contaminating effect of the residual atmosphere.

The practical applications of thin films generally make use of properties which are structure-sensitive, but in no application is the anomalous structure anything but a disadvantage. If it is shown that bulk metal or bulk dielectric characteristics can be reproduced and maintained at normal temperatures in thin films by the use of ultra-high vacua, then this would be an enormous practical advantage. If, on the other hand, we must continue to put up with films of aggregated structure for practical purposes, research on films produced in every vacuum system will have to continue side by side with strictly academic research at lower pressures.

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Instrument for recording the dust nuisance emitted by chimneys

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Abstract

A new type of instrument has been designed to measure and record the likelihood of dust emitted from a chimney causing nuisance at ground level. The instrument measures the difference between the optical obscuration produced by a clean glass surface and that produced by the same glass surface when dust collected from a flue duct has settled on it. The method of collection is based on the assumption that vertical surfaces are more important in pollution than horizontal surfaces, and that coarse particles are more likely to cause nuisance than fine particles. Care has been taken in the design to eliminate errors normally associated with optical instruments of this nature, for example those caused by a dirty optical system, ageing photocells and lamps, and mains voltage and temperature fluctuations.

The instrument has a novel recording method which enables it to operate over an unusually large range of signal levels. It will facilitate the control of dust emission from industrial chimneys.

Introduction

ALL coal-burning furnaces and, to a lesser extent, oil-burning furnaces, carry considerable quantities of ash, some of which is finely divided and is likely to be lifted by the velocity of the furnace gases, and emitted from the chimney, to the detriment of the neighbourhood. When the coal itself is finely divided, as in pulverized-fuel furnaces, the problem is, of course, intensified. For all large furnaces, and for all furnaces burning pulverized fuel, it is now mandatory to instal dust-collecting plant, so that the pollution of the neighbourhood is minimized.

Modern plant is capable of such high efficiency in combustion and electrostatic precipitation that when it is suitably designed and maintained in perfect order there is no likelihood of offence being caused. However, if there is some degree of failure in the plant, there is a possibility of objectionable emission. It is therefore desirable to monitor the flue gases leaving a chimney, so that a record is obtained which either gives proof of satisfactory operation or gives warning of failure. It is also desirable to monitor effluent gases to ensure that the plant maintains the expected standard of performance and justifies the capital and running costs involved.

Instruments already exist which measure the optical density of the flue gases and these indicate the degree of nuisance caused by large visible plumes and by the obscuration of sunlight. However, they give little indication of the likelihood that dust will settle on the ground, or cause complaint by settling on laundry, obscuring the surfaces of houses

and trees, or entering open windows. The present instrument (British Patent Applications No. 6121/58 and No. 31283/58) is intended to give warning of this type of nuisance. It is designed to collect the amount of dust which would impinge on a surface of unit area placed at right angles to the gas stream and to measure the optical obscuration of the surface produced by this amount of dust. It has been designed in this way because it is considered that this measurement is closely related to the likelihood of dust pollution at ground level. Unlike the existing optical-density instruments, on a weight-for-weight basis, it is more sensitive to coarse dust than to fine dust.

The theory of dust pollution on which the instrument is based is discussed more fully in a paper to be published in the *International Journal of Air and Water Pollution* in April 1961.

Description of the instrument

The instrument consists of three units, the collecting and measuring unit, the control unit and the recorder. The collecting and measuring unit is attached to the side of a horizontal duct leading to the stack, with the sampling head inside. The instrument sampling head is shown in Figure 1. A small horizontal duct A faces into the gas stream. This leads into a vertical duct B of equal cross-sectional area which is closed at the top and bottom by glass plates C and D. The flue gas does not enter the duct A since there is no outlet but is deflected around it, carrying the very fine dust with it. The coarser particles are carried by inertia into B, and settle in a random manner on the lower glass plate D. The duct B is sufficiently long compared with its width to prevent turbulent gas movements reaching the glass plates, and settled dust is therefore undisturbed.

Parallel light from a lamp on the outside of the duct is directed by means of a system of lenses and prisms through the plate D and back to the outside of the duct. Here, the light is focused on to a cadmium-sulphide photoconductor cell, after passing through an annular optical wedge. The wedge has a linear density variation from 0 to 2 and can be rotated by means of a reversible electric motor so that obscuration of the light beam can be varied. Light from the same lamp bulb also falls directly on to a second similar photoconductor, after passing through an iris diaphragm. The light falling on the two photoconductors allows a current to pass in each when a voltage is applied across them.

The optical wedge is used to make the current in the measuring photoconductor equal to the current in the other first before dust collects and, second, after dust has collected for a predetermined time. The amount of wedge movement required after the dust has collected is a measure of

ected dust (see Appendix). The details of the complete
ence are as follows.

g. 2 is a combined circuit diagram of the three units of
instrument. The control unit can be placed in any con-

third pair of contacts on RLA. The diagram shows the
various switch positions with the relays unenergized. Each
photocell is in series with one of the two coils of RLE. The
current in the compensating arm remains constant during the

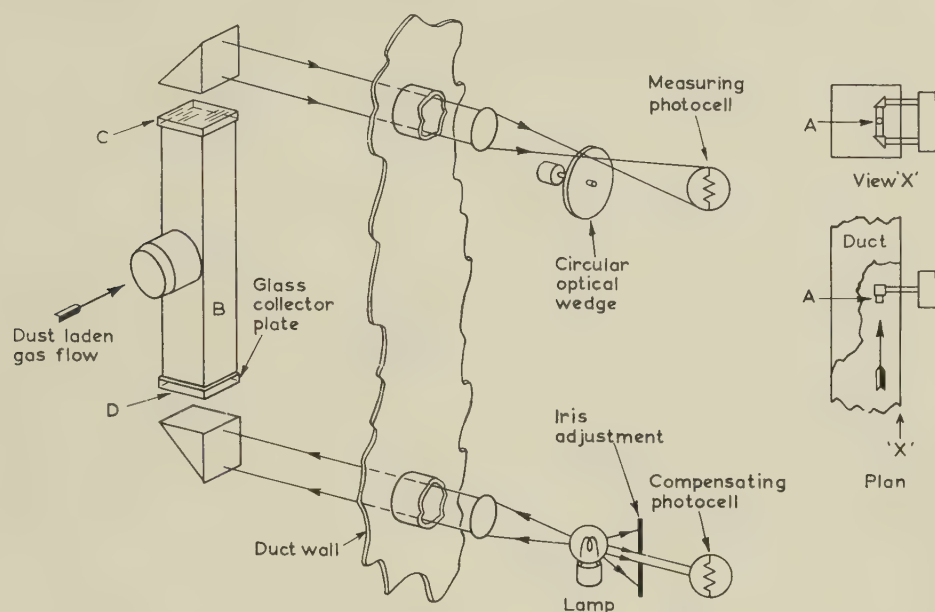


Fig. 1. Diagrammatic view of optical system.

ent part of the station reasonably near the measuring
. It consists of a system of relays, actuated by a master
ferential relay, RLE, which is actuated by the difference
ween the currents from the two photoconductors. Relays
A, RLB, RLC, RLD, RLF and RLG are four-pole, double-
nge relays, the contacts on each relay being designated
he relay letter and a suffix thus: A₃, for example, is the

cycle of operations, set by means of the iris control, while
that in the measuring arm varies:

- with the amount of dust collected,
- with the position of the optical wedge.

At the start of a cycle, the glass plate D is clean, and the
wedge position is such that the currents through the two

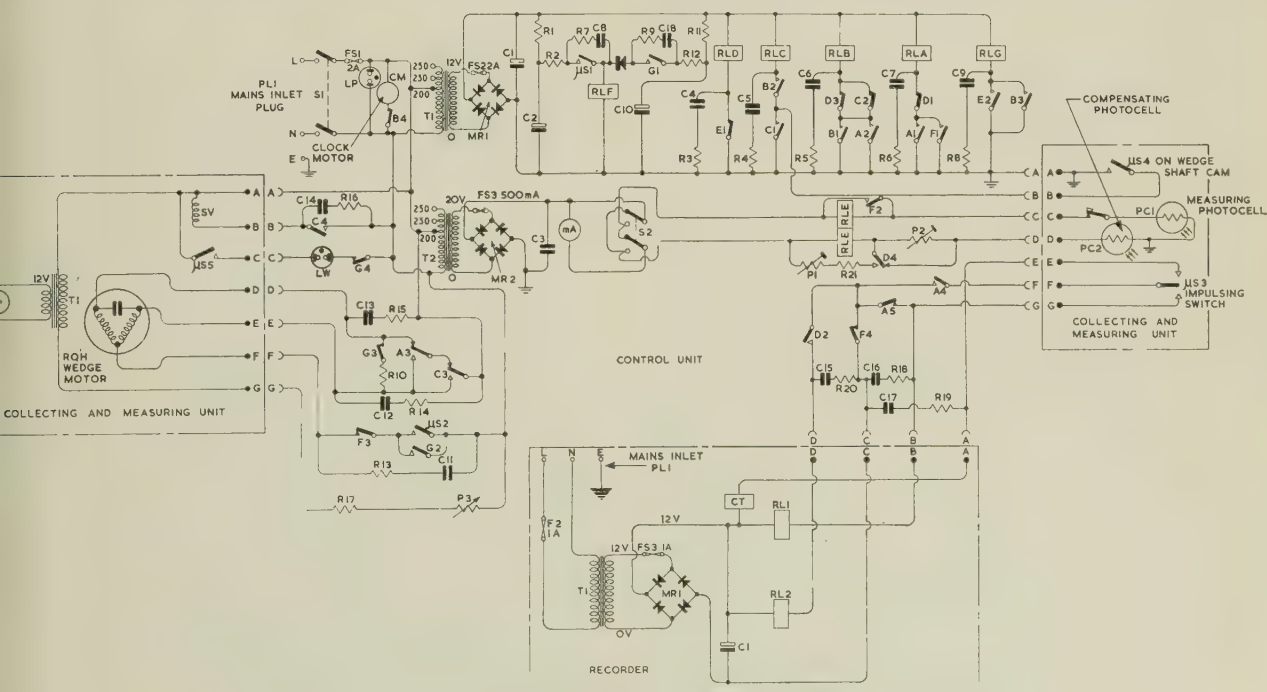


Fig. 2. Recording flue dust monitor.

photocells are equal. In this position, the wedge is stationary, RLD is energized, and relays RLA, RLB, RLC, RLF and RLG are de-energized. As dust collects, the current in the measuring arm of the control relay falls.

After a pre-set collecting time, the timer closes micro-switches μS_1 and μS_2 , to initiate a measuring cycle; μS_1 discharges a large electrolytic capacitor through RLF, causing it to be momentarily energized. This relay is operated for a sufficient period to energize relays RLA, RLB, and RLG, and to de-energize RLD.

The function of RLG is to set the wedge motor in motion. A notched wheel on the wedge motor shaft operates a micro-switch which supplies impulses to an impulse recorder, and to a counter, in proportion to the amount of rotation of the wedge. With RLA energized, the direction of rotation of the wedge is such that the light falling on the measuring photocell increases. In addition, contacts A_4 complete the impulsing circuit, so that when a measuring cycle is initiated, the impulse recorder draws a line on its chart, and a number of pulses is indicated on the counter, the length of the line being proportional to the rotation of the wedge.

The optical wedge continues to rotate until the currents in the two arms of the control relay are equal, at which point RLE operates, energizes RLD and de-energizes RLA. The combination of these two relays reverses the wedge motor, stops further impulses from being transmitted, and completes a zeroing circuit in the recorder. The counter continuously adds the individual recordings on the chart.

The wedge now moves in the direction of increasing density, and at one point, RLE will again operate and de-energize RLD. When the most dense part of the wedge obscures the light beam, a microswitch, μS_4 actuated by a cam on the wedge shaft closes and energizes RLC. This reverses the wedge motor once again, and at the same time switches on a blast of clean compressed air, which is directed on to the glass plates at the top and bottom of the collector box, clearing the collected dust back through the entrance hole into the flue duct.

The photocell current now increases until the currents in the two coils of RLE are again equal, when RLE operates, energizes RLD, which in turn de-energizes RLB, RLC and RLG. The wedge motor and air blast are stopped, and the state of the relays is exactly as it was at the beginning of the cycle. The instrument is now said to be standardized.

When dust is collecting in the collector box, RLD is energized and contacts D_4 are so arranged that a proportion of the current in the compensating photocell bypasses that coil of RLE through the resistor P_1 . When standardizing, or making a measurement, RLD is unenergized and the compensating coil takes the full current. The differential of RLE is set fairly low, about 0.2 mA compared with the compensating current of approximately 5 mA, so that the amount of dust which needs to collect before RLE is actuated is dependent mainly on the setting of the resistor P_1 .

Should sufficient dust collect to make the currents in the two coils equal, in spite of some of the current being bypassed, RLE operates and this energizes RLG which initiates a normal measuring cycle without waiting for an impulse from the timer. In this way, it has been possible to extend the useful range of the instrument. Experience in power stations has shown that, at periods of peak load, and when a fault exists, dust burdens of more than 100 times that under normal load conditions may be encountered. The sensitivity of the instrument has been adjusted so that, under ideal conditions, a small reading of the order of 10% full scale is indicated every 15 minutes. P_1 has been set so that

as soon as the dust burden exceeds that which would produce a reading of approximately 70% full scale, irrespective of the time taken, the instrument records it. In cases of heavy dust burden, therefore, the correct reading is the sum of the readings in a 15 minute timing interval. An alarm has been incorporated in the recorder which can be pre-set to operate at an excessive level of nuisance.

Apart from the range of signals experienced at one station the normal level of dust emission varies greatly from station to station. To meet the requirements of a station where the normal level is high, a cone with a reduced entrance area may be attached in place of the entrance duct A. The sensitivity in this case is reduced in proportion to the reduction in area.

Since the time taken to make a measurement varies with the amount of dust collected, the timer motor is stopped during a measuring cycle in order to keep the collecting time constant.

In order to prevent the loss of a few impulses because of the over-run of the wedge motor after standardization, the motor is electrically stalled at the end of a measuring cycle by connecting the two phases of the motor in opposition. This would overheat the motor if the condition was prolonged, and a microswitch, μS_2 , on the timer motor disconnects the supply when it is not required.

Principle of the light intensity measurement

From the description of the operation of the instrument it can be seen that the dust monitor makes a measurement of the clean glass plate at the end of one cycle, which is recorded on the chart or counter, and after a timed period during which dust is collected, a further measurement, at the difference between the two measurements is recorded. The maximum time between the two is 15 minutes. Consequently, any gradual changes which could affect conventional light-intensity measurements, ageing of photocells or lamp changes of ambient temperature, dirtying of the optical system or long-term voltage variations, will be compensated for since they affect both readings equally. In fact, the wedge is the only part of the system which, if dirty, could produce an error, and care has been taken to keep it clean. Both during standardizing and measuring movements are made with steadily increasing light. If this were not so, the two positions of balance might differ by the differential of relay error. Any reasonable value of the differential does not produce error.

It is true that sudden changes which take place during the collecting period are not compensated for by this method. For example, a voltage fluctuation is possible, especially at a power station, where large auxiliaries are likely to be switched on and off frequently. It has been found that inclusion of the second compensating photocell reduces errors caused by a fluctuation of 5 v during the collecting period from 6% to 1% full scale. The compensating photocell is not matched with the measuring photocell, being taken from a batch as supplied by the manufacturer. The matching of photocells is not practicable, for photocells which may be chosen as a matched pair when new would not necessarily remain so.

Although the compressed-air cleaning system is very efficient, it is inevitable that the glass plates, and in fact the sealed optical system, will get dirty in time. An automatic shift in the standardized position of the optical wedge compensates for this, but after a time the amount of wedge movement required for compensation may become so great

insufficient is left for measurement. A warning lamp is on the front panel of the control unit to indicate when the standardization position of the wedge has passed the zero-way mark. This does not necessarily mean that the optical system needs to be cleaned. The light intensity can be increased using the lamp control knob on the front panel, the standardization position adjusted by means of the screw in the measuring unit. It is only when the limit of these adjustments is reached that the optical system needs cleaning.

Testing and experience

(a) *Calibration.* The instrument was set up with the sampling duct facing into an 8-in. diameter horizontal pipe, in which air was flowing at a velocity which could be varied up to about 80 ft/s. Weighed quantities of dust of various grades were introduced into the pipe through a funnel 15 diameters upstream from the instrument. For a given quantity of dust a measurement was obtained on the instrument. Fig. 3 shows the response of the instrument to

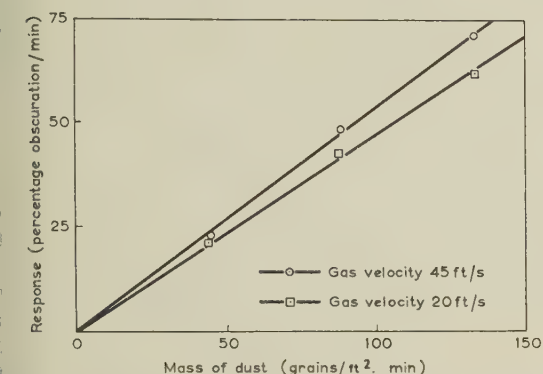


Fig. 3. Variation in response with mass of dust at different gas velocities.

different weights of dust of the same grading between $50\ \mu$ and $70\ \mu$ (approximately 20 vel*) at 20 and 45 ft/s gas velocity. The variation is linear. The reason why it is not arithmetic is given in the Appendix. The curves also show that the response to a given weight of dust is not very dependent on gas velocity. However, the weight of dust passing through a flue duct in a given time will be given by the product of dust concentration and gas velocity and in this sense the response is proportional to velocity.

Fig. 4, curve 3, shows the results obtained when dust samples separated according to terminal velocity are used, and illustrates the progressive change of sensitivity over the range of dust coarseness which is a feature of the instrument. The response of the instrument has been calculated on theoretical grounds assuming (a) that collection is due to inertia, (b) that collection is due to diffusion, and the results are shown in curves 1 and 2. It is apparent that for 100 vel particles, the theory that the particles penetrate to the back of the collector box by sheer inertia is largely true. However, as the particles become finer, they become much more affected by the high degree of turbulence in the entrance to the box, and have an increasing chance of escape by diffusion.

The measured response can be explained by assuming that both effects are relevant over most of the range from 1–100 vel.

A 1-vel particle has a free falling speed of 1 cm/s in still air (I.P.P.).

The relation between the two effects moves from a state where inertia is predominant at 100 vel to a state of balance at about 10 vel, and wholly in favour of diffusion for sub-micron dust.

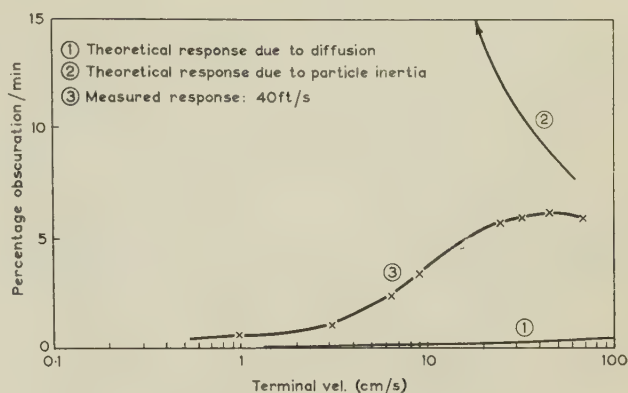


Fig. 4. Theoretical and actual response of instrument.

Dust rate assumed to be 10 grains/ft² passing collecting head per minute. Density assumed to be 1.2.

The theory of dust sampling (Davies 1954) with aspirated nozzles suggests that inertia is predominant at all sizes down to 5 vel.

(b) *Interpretation of readings.* The sensitivity of the instrument has been fixed arbitrarily so that a 70% scale reading implies that a vertical surface exposed in the duct will become 7% obscured in one minute. It is essential to be able to relate the readings of the instrument expressed in percentage obscuration per minute to the likelihood of nuisance. In the last resort this can only be done by experience. However, it is desirable to fix levels provisionally, so that a standard exists which can be tested by experience. The arithmetic of this process is fairly complicated (*Int. J. of Air and Water Pollution*, to be published) but, as an example, it can be stated that if the effective height of emission is 250 ft, if the area of cross section of the duct is 50 ft² and there are no other sources of dust pollution, 9% obscuration per minute is allowable indefinitely, 27% obscuration per minute is allowable for one hour, 94% obscuration per minute is allowable for $\frac{1}{4}$ hour, and 1350% obscuration per minute is allowable for one minute. It will be realized that although the instrument normally registers only every 15 minutes, if the emission becomes higher than is tolerable for a period of 15 minutes, the instrument responds much more quickly.

Although the instrument reads percentage obscuration per minute, this result can be approximately converted to grain/ft² per second if the grading of the dust is known.

(c) *Experience in power stations.* A number of instruments has been installed in power stations, primarily to test and improve the serviceability of the instrument but, in addition, a limited amount of information on power station performance has also been obtained. It was found necessary to redesign a number of minor points. For instance, an improved pen and ink reservoir has been provided and several materials for use as gaskets to seal the instrument from the flue gases have been tried out. It has been found that silicone rubber is generally satisfactory but is not completely immune from attack by sulphuric acid. Klingerit gaskets are successful if they are sufficiently resilient to fit the glass. The glass collecting surface is now made of Technoplate, an armoured glass, instead of ordinary glass, which was liable to crack. The use of transistor-type photo-

cells was discontinued because they were far too sensitive to the changes of temperature which occur from station to station and from time to time. The cadmium-sulphide photocells give satisfactory performance over a range of temperatures from 0°C to 65°C .

One of the most alarming discoveries of the experimental period was that dust burdens on occasion were very much higher than had been expected, and in addition to the built-in ability of the instrument to record more rapidly under these conditions, it was necessary to make use of reducing cones on the sampling head. As a result of this experience, the present design of instrument is approximately half as sensitive as the original design.

In many cases the instrument can be installed in a horizontal duct, but in other cases it is only convenient to use a vertical duct with the gas flowing either upwards, as in the chimney,

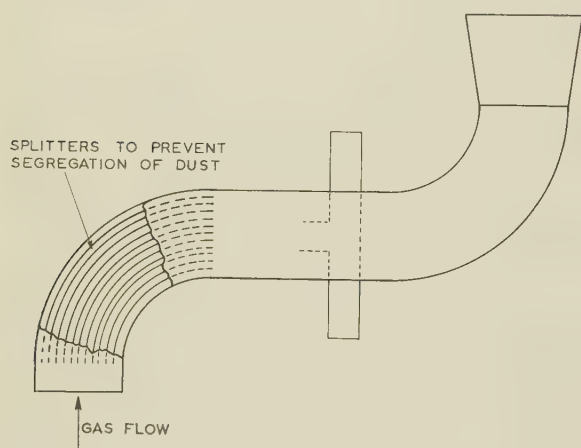


Fig. 5. Adaptor for use in vertical duct (can be inverted for downward gas flow).

or downwards, as in the duct leading to the induced draught fan. In these cases, a modification to the sampling head shown in Fig. 5 has been found to work satisfactorily without apparently changing the calibration of the instrument.

On a number of occasions the instrument has been used to assess the effect of different modifications of power station operation on dust emission. In this limited experience, change of boiler load appears to have the most dramatic effect on dust emission and an increase from 85% of full load to full load can increase the nuisance value of the dust emitted by a factor as much as 10.

A change in the coarseness of grinding also has a marked effect and at one power station when the mill classifier was bypassed the reading of the instrument increased by a factor of 2. It is of interest to record that the reading of an optical density type instrument was appreciably reduced at the same time.

Although the instrument was designed primarily to measure dust emission, tests have been carried out at two oil-burning stations to discover whether it would satisfactorily record the emission of acid smuts. It was found to be most successful and is being used to give immediate information of the dependence of acid smut emission on various operational changes in the power station. As a precaution, smut heaters were added to the sampling head to minimize the risk of acid attack under these conditions.

A composite chart has been prepared (Fig. 6) to illustrate the kind of record provided by the instrument. It shows the normal rise in emission as the load on the station reaches a peak at 8.30 a.m.; the effect of a fault in the classifying of pulverized fuel at noon and the temporary breakdown of precipitator at 3.40 p.m.

Acknowledgments

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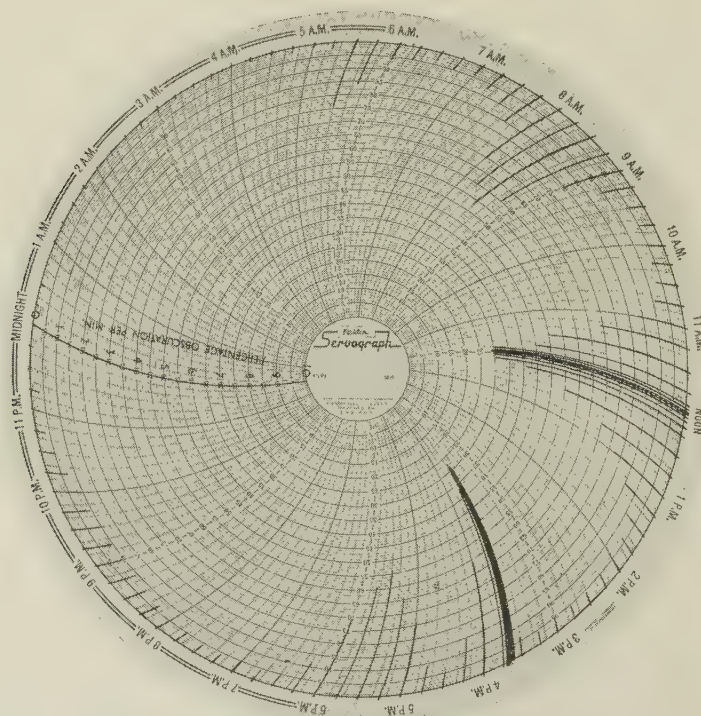


Fig. 6. Chart illustrating kind of record provided by instrument.

knowledge is made of the assistance of our colleagues Research Laboratories and at a number of C.E.G.B. power stations, particularly Earley Power Station, where the first prototype was tested out.

Appendix

Calculation of response of recorder and counter

As the optical wedge is turned from density 0 to density 2 emits 216 pulses. Hence $d = P/108$, where d is density any point P pulses from density 0. That is,

$$\log_{10} \frac{I_0}{I} = \frac{P}{108}; I = I_0 \times 10^{-\frac{P}{108}}$$

where I_0 is the initial and I the final light intensity. If dust of a total cross-sectional area a is deposited on area A , the fraction of light transmitted will be

$$e^{-a/A} \text{ or } 10^{-(a/A)\log_{10} e}$$

with clean glass,

$$I = I_0 \times 10^{-P_1/108}$$

with dirty glass

$$I = I_0 \times 10^{-P_2/108} \times 10^{-(a/A)\log_{10} e} = I_0 \times 10^{-P_2/108 - (a/A)\log_{10} e}$$

Since I is maintained constant,

$$\frac{-P_1}{108} = \frac{-P_2}{108} - \frac{a}{A} \log_{10} e$$

Hence $\frac{a}{A} = \frac{P_1 - P_2}{108 \log_{10} e}$ and the response of the instrument is

linear with respect to a . If

$$P_1 - P_2 = 1, \frac{a}{A} = \frac{1}{108 \log_{10} e} = \frac{1}{108 \times 0.4343} = 2.13\%$$

Hence 1 pulse recorded on the counter corresponds to an obscuration of 2.13%.

The chart is calibrated such that 10 divisions correspond to 1% obscuration per min. Hence the number of pulses in one counting period of 15 minutes to give 10 divisions deflection must be $(1\% \times 15)/2.13\%$, that is 7.

The movement of the pen per pulse is adjusted so that seven pulses give a deflection of ten divisions.

Reference

DAVIES, C. N., 1954, *Dust is Dangerous* (Faber and Faber).

platinum resistance thermometer for use at high temperatures

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(Communication from the National Physical Laboratory)

paper first received 17th August 1960 and in final form 21st September 1960

Abstract

The design and performance of a platinum resistance thermometer for high temperatures are described. The thermometer bulb is 36 mm × 5.5 mm and is contained in a recrystallized alumina sheath 500 mm long and 8 mm external diameter. The coil is wound from very pure platinum wire ($\alpha = 0.003926$) of diameter 0.3 mm and is freely exposed to dry air. The coil resistance at 0°C is 1.4 Ω and this permits measurements to the equivalent 0.002 deg C. The thermometer is found to be stable over this limit on heating it for one hour at 1063°C.

Introduction

THE platinum resistance thermometer is well established as a high-precision instrument over a wide range of temperatures. In particular, it is the chosen intercomparison instrument for the International Temperature Scale over the temperature range from -182.97°C, the boiling

point of oxygen, to 630.5°C, the freezing point of antimony. At present, efforts are being made to extend the range of the platinum thermometer in this role to both higher and lower temperatures. At low temperatures, in order to limit the differences in the resistance-temperature relationships, it is necessary to put stringent limits on the purity of the platinum used, while at high temperatures it is necessary to find a suitable design of thermometer to limit the changes resulting from exposure to high temperatures, such as evaporation of platinum and contamination. At any temperature it is desirable that the thermometer bulb should be small to get a low value of the lag-constant and to make it easy to maintain uniform temperature conditions over the whole of the bulb. The size of the bulb is particularly important at high temperatures because the provision of uniform temperature conditions is more difficult than at lower temperatures where stirred liquid baths can be used to give good heat transfer. The design of thermometer described here for use up to the freezing point of gold (1063°C) is a compromise between that required for good stability and that for small dimensions.

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Thermometer construction

Previous designs of thermometer by one of the authors (Barber 1950, 1955) have all employed simple helices of platinum wire of small diameter provided with the minimum of support so that they remain unconstrained when the temperature changes. The present design, a general view of the bulb of which is shown in the photograph, Fig. 1, is similar in

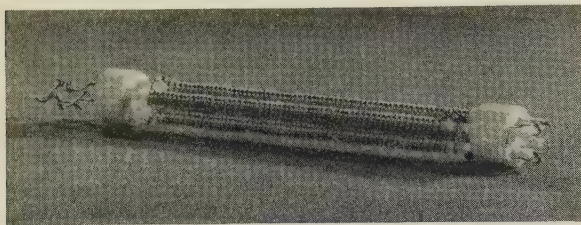


Fig. 1. Bulb of high-temperature resistance thermometer.

principle. The salient features of this design making it suitable for use at high temperatures are as follows. The material used for support of the coils and for sheaths is pure recrystallized alumina which is highly refractory and capable of being carefully cleaned, thus reducing the risks of contamination of the platinum wire. The diameter of the bulb wire, 0.3 mm, is much thicker than is used for the normal range of temperature, in order to reduce the effects of evaporation and contamination of the wire. Other designs of platinum resistance thermometer for the same temperature range have been described (Moser 1930)* and these employ thicker bulb wire (0.5 mm diameter) and have a much lower resistance than the thermometer described here (0.1 to 0.2 Ω as compared with 1.4 Ω), and could not be measured with the required precision on the N.P.L. Smith bridge. Another feature of our thermometer is that there is free access of air, after being dried, to the thermometer coils and this appears to give a better stability than when the thermometers are sealed either in air at a reduced pressure ($\frac{1}{3}$ atm.) or in an inert gas such as helium, nitrogen or argon. This point is by no means definitely proved, but previous attempts by one of the authors (C.R.B.) to produce thermometers employing these atmospheres were not successful from the point of view of stability. It is of course well known that the risks of contamination of platinum are very much less in an oxidizing than in a neutral or reducing atmosphere.

The details of the construction of the thermometers are as follows. Four coils of platinum wire are loosely mounted on four recrystallized-alumina tubes which are held parallel to one another by two circular disks, one at each end, having holes in them into which the alumina tubes fit. A cross-section of the coil assembly showing the detail of two of the four coils is shown in Fig. 2. The coils are wound from wire 0.3 mm in diameter on a steel rod 0.9 mm in diameter, 250 mm of wire being required for each coil, which is about 36 mm long. They are removed from the rod and the ends are bent into suitable positions for welding and then the coils are cleaned by boiling them in dilute nitric acid and in distilled water several times. The tubes and disks for mounting the coils, the insulating tubes for the platinum leads and the protecting sheath are heated in a furnace to 1100° C with free access of air to oxidize away carbonaceous material. The bulb is now assembled, the coils being threaded on to the alumina tubes which are of 0.4 mm bore,

0.8 mm outer diameter and 50 mm length, and the ends of the tubes being inserted into the four holes in the disks. These holes are 1.2 mm in diameter and this is sufficiently large to permit the four platinum leads (0.3 mm diameter) which pass through the tubes carrying the coils, to be threaded through one of the disks side by side with the tubes.

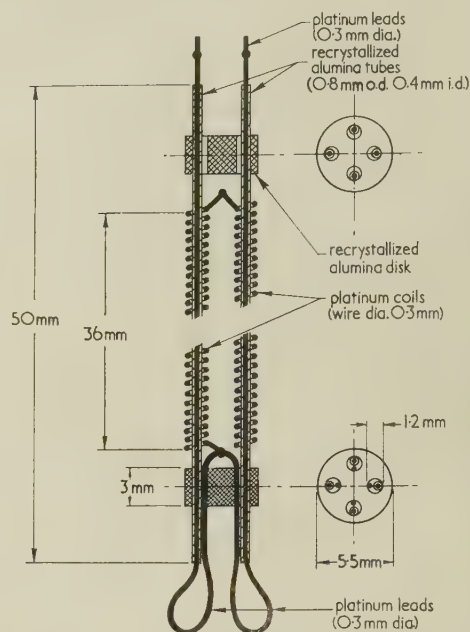


Fig. 2. Cross section of coil assembly showing two of the four coils.

The leads are fused to appropriate coils at the lower ends to provide current and potential leads, and the coils are fused to one another in series, the joints being made in a fine oxy-coal-gas flame. At this stage, the assembly is brushed with benzene to remove grease contamination from the handling operation and then heated to 1000° C in a furnace. The four leads from the bulb to the head of the thermometer consisting each of 150 mm of 0.3 mm platinum wire at the lower end and the rest of 0.5 mm platinum wire, are carried in a four-bore alumina sheath 5 mm in outer diameter. The outer sheath is of recrystallized alumina and has an outer diameter of 8 mm, an inner diameter of 6 mm and a length of 500 mm. The leads are bent over the edge of the sheath and a closely fitting glass cap is pushed over them and sealed on with a high-melting-point wax. A small hole is left in the wax to permit free access of air to the thermometer bulb. The platinum leads are hard-soldered to polythene-insulated copper wires and the joints are bound to the sheath with adhesive tape using sheet polythene to insulate them from one another, and then covered with several layers of the aluminium sheet to promote temperature uniformity. The head of the thermometer is a glass tube which is sealed to the alumina sheath by a rubber gasket. The head contains silica gel to keep the air in the thermometer dry.

Annealing and stability

The annealing treatment of the four thermometers constructed was governed by the experience gained with one of them, thermometer HT3. The thermal history of this thermometer is shown in Fig. 3. It is seen that repeated heating at 800° C does not produce a stable condition, the resistance R_0 falling after each of five two-hour periods

* See also *Procès-Verbaux des Séances du Comité International des Poids et Mesures* 1954, 24, T126.

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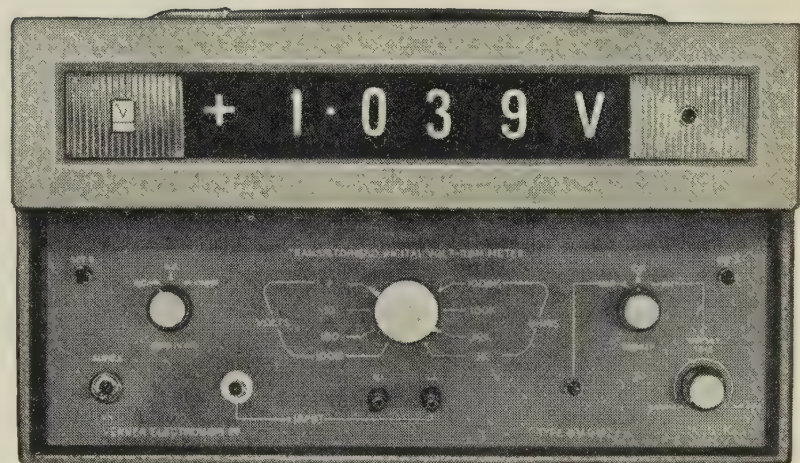
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56UVP As 56AVP but with quartz end window.

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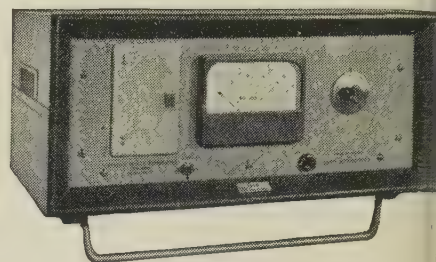
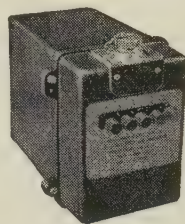
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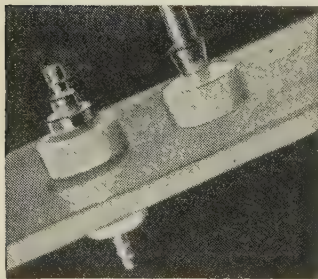
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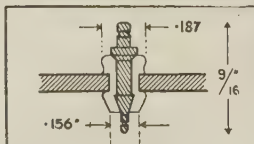
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ng. After several hours at 1063°C, however, good stability of R_0 and of the temperature coefficient of resistance obtained. The thermometers HT4, HT5 and HT6 were heated for one hour at 1100°C before making the stability tests the results of which are shown in the graphs, Fig. 4.

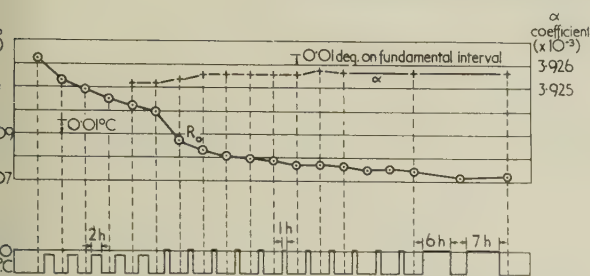


Fig. 3. Stability of thermometer HT3 with heating cycle.

these tests, R_0 and α measurements were made after heating for separate one-hour periods at 1063°C, and thermometers HT4 and HT6 were found to be stable under these conditions to the limits of accuracy of the measurements, namely 1 in 140000 in R_0 equivalent to about

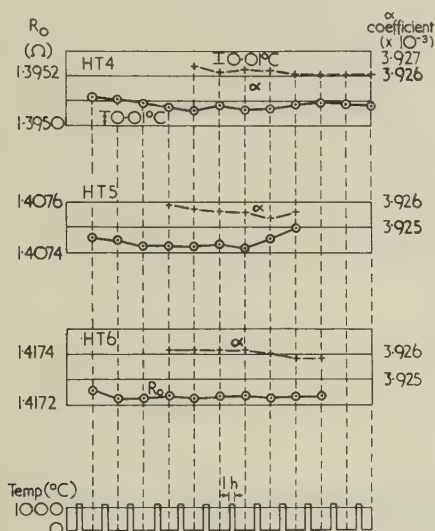


Fig. 4. Stability of thermometers HT4, HT5 and HT6 with heating cycle.

2 deg c. Thermometer HT5 was less stable and its resistance element broke in the furnace during the tests. It was thought that the instability might have been caused by the presence of a crack in the tube before the break occurred. For the stability tests were made with the thermometers

heated in the horizontal position with the exception of the last four one-hour periods and the six- and seven-hour periods of heating at 1063°C of thermometer HT3 (Fig. 3), which were for the vertical position. The thermometer performed equally well in the two positions suggesting that fairly long periods of heating at 1063°C are possible in the vertical position without trouble due to sagging of the coils.

Since it is difficult to interpret the changes in R_0 and α in terms of changes at the high temperatures, further stability tests were made on thermometer HT3 by heating it in a uniform-temperature zone in a furnace at 1063°C for 146 hours, simultaneous readings being made from time to time of the resistance of the thermometer and of the e.m.f. of a platinum/10% rhodium-platinum thermocouple placed adjacent to the thermometer bulb. On the assumption that the platinum thermocouple remained constant in its calibration, a steady upward drift of the resistance of the thermometer was observed equivalent to 0.27 deg c over the complete period of 146 hours corresponding to a rate of change of 0.0018 deg/hr. If the calibration of the thermocouple had changed on account of exposure to the high temperature, the e.m.f. would have fallen and this would tend to exaggerate the apparent rise in resistance of the thermometer. The stability may therefore turn out to be better than indicated. A rise equivalent to 0.002 deg/hr, however, may be regarded as a satisfactory degree of stability for using the platinum thermometer as a standard instrument of the International Temperature Scale up to 1063°C.

Summary

A platinum resistance thermometer suitable for use up to the freezing point of gold, 1063°C, has been constructed. The overall dimensions of the resistance element are 36 × 5 mm and those of the containing sheath are 500 × 8 mm. The resistance of the thermometer is about 1.4 Ω at 0°C and about 6.4 Ω at 1063°C and can be measured with sufficient precision on the N.P.L. design of Smith bridge to give a sensitivity of 0.002 deg c. It has been shown that heating the thermometer for successive one-hour periods at 1063°C produced negligible changes in R_0 and α ; a prolonged period of heating of 146 hours at 1063°C caused a rise of the resistance at 1063°C corresponding to 0.002 deg/hr. It is concluded that the design is suitable for the purpose of defining the International Temperature Scale up to 1063°C.

The work described in this paper was undertaken as part of the research programme of the National Physical Laboratory and is published by permission of the Director of the Laboratory.

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Automatic correction of counting losses in a Geiger-Müller counter used with periodically varying radiation

by B. B. TROTT, B.Sc., Ph.D.,* Viriamu Jones Laboratory, University College, Cardiff

Paper first received 30th October 1959 and in final form 15th September 1960

Abstract

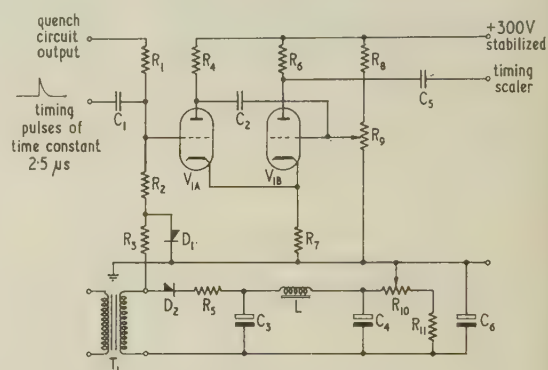
Correction is achieved by reducing the number of uniformly-spaced timing pulses recorded during the reception of a particular number of pulses from the counter. The action and performance of a circuit which restricts to a suitable portion of the radiation cycle the registration of timing pulses is described.

DEN HARTOG and Muller (1950) have suggested that if a Geiger-Müller (G-M) counter is used with a quench-circuit, and the experiments are timed with an electronic pulse generator and counter, then the dead-time corrections may be made automatically by suppressing the timing pulses during the quench period. The timing counter then records only during the time for which the G-M counter is sensitive. This method cannot be used in its original form in an x-ray diffractometer with a self-rectifying tube, since the effective dead-time of the G-M counter in this case is greater than the quench-pulse length by a form-factor of approximately three (Arndt 1949). It was thought, however, that this difficulty could be overcome by restricting the timing pulses to a part of the voltage cycle during which the average x-ray intensity was greater than the overall average by a similar factor. The same principle would apply if a G-M counter were used with other radiations which varied periodically in intensity.

Experiments were carried out with the circuit shown in the figure. The timing scaler is supplied with pulses from the output of the Schmitt trigger circuit (Farley 1956) formed by V_{1A} and V_{1B} ; the pulses from the timing generator operate this circuit only if the bias on the grid of V_{1A} lies between appropriate limits. The bias is determined by the output of the quenching circuit (Eastabrook and Hughes 1953) and the voltage E_1 at the lower end of R_3 . The upper end of R_1 is taken to a point in the quenching circuit which is normally 240 v above earth, but which falls to earth potential during the quench pulse. The voltage E_1 is made up of the alternating output of the transformer T_1 , which must be in phase with the x-ray tube h.t. voltage, superimposed on a steady negative voltage which is derived from the output of T_1 and varied by adjustment of R_{10} . If the counter is not quenched, and if E_1 is positive or barely negative so that D_1 conducts, then the grid potential of V_{1A} is steady, and is set at 1v below the triggering level of the Schmitt circuit by adjustment of R_9 . The 2v timing pulses are therefore passed on to the timing scaler. If the G-M counter is quenched, or if E_1 is appreciably negative, then the grid potential of V_{1A} falls and the timing pulses are sup-

pressed. Adjustment of R_{10} restricts the timing pulses to the appropriate part of the voltage cycle.

The mean frequency of the timing pulses depends to some extent on the stability of the voltage E_2 fed to the input of the transformer T_1 .



Circuit for automatic dead-time correction with Geiger-Müller counter and a self-rectifying X-ray source.

$R_1 = 10 \text{ M}\Omega$
 $R_2 = 2 \text{ M}\Omega$
 $R_3 = 100 \text{ k}\Omega$
 $R_4 = 10 \text{ k}\Omega$
 $R_5 = 100 \Omega$
 $R_6 = 2 \text{ k}\Omega$
 $R_7 = 10 \text{ k}\Omega$
 $R_8 = 150 \text{ k}\Omega$
 $R_9 = 0-50 \text{ k}\Omega$
 $R_{10} = 0-5 \text{ k}\Omega$
 $R_{11} = 5 \text{ k}\Omega$

$C_1 = 10 \text{ pF}$
 $C_2 = 100 \text{ pF}$
 $C_3, C_4 = 8 \mu\text{F}$
 $C_5 = 0.01 \mu\text{F}$
 $C_6 = 8 \mu\text{F}$

$D_1, D_2 = \text{GEX54}$

$L_1 = 20 \text{ H}$

$V_1 = \text{Mullard ECC85}$

$T_1 = 230\text{V}/34\text{V (r.m.s.)}, 50 \text{ c/s.}$

extent on the stability of the voltage E_2 fed to the input of the transformer T_1 . For example, with a typical setting of R_{10} , and in the absence of G-M counts, approximately 3000 timing pulses per second out of 10000 were passed to the timing scaler. An increase of 10% in E_2 then produced a decrease of 2% in the mean number passing. This variation could be reduced by making the output of T_1 greater (relative to the timing pulses) than the 34 v r.m.s. used. Distortion of the waveform of E_2 also affected the number passed and poor timing stability was apparent when E_2 was obtained from a constant-voltage transformer of moderate quality. Some statistical variation is to be expected in the mean frequency of the timing-pulse output, since it is partly controlled by the counter quench-pulses, which begin at random epochs. If, however, the number n of timing pulses suppressed in a given time by the action of the quench pulses varies, as seems likely, in accordance with a Gaussian distribution of standard deviation $n^{-1/2}$, then the increase in the statistical variation of measurements should be negligible.

The G-M counter was mounted on an x-ray diffractometer which was used with Cu $K\alpha$ radiation. The counter was operated at a low overvoltage (40 v above the threshold of 1360 v) to reduce the effect of 'proportional' counting.

* Now at Brush Electrical Engineering Company Limited, Loughborough.

ing the quench pulse. The magnitude of the quench pulse was 240 v. For the measurement of steady radiation, as suggested by Den Hartog and Muller, the quench pulse could be made longer than the full recovery time of the counter (700 μ s for the counter used) in order to eliminate dead-time losses completely. In the present case a quench pulse of 300 μ s (a little longer than the counter dead-time of 200 μ s) was used with the idea of minimizing the increase in the form-factor at high counting-rates. In practice, the effective dead-time of the system was found to be constant for x-ray intensities up to a counting-rate of 400 per second. The dead-time was found by measuring the apparent attenuation of a single nickel foil at various x-ray intensities (Trott 1959, 1960). The effects of varying the overvoltage and the quench-pulse length were not investigated.

It was found possible to reduce the apparent dead-time of the system through zero to negative values. With 42 kv peak voltage applied to the x-ray tube, exact correction was obtained when the steady component of E_1 was 0.55 of the peak value of the a.c. component. An increase of 1 v (approximately 1%) in the bias decreased the dead-time by 100 μ s near the zero setting. The apparent dead-time was highly sensitive to variations in the voltage E_3 supplied to the X-ray h.t. generator: in one case a 10% decrease in E_3 produced an increase of 300–400 μ s in the dead-time. However, E_2 was obtained from a tapping on the input transformer of the h.t. generator, and much of this variation in the dead-time may have resulted from consequent distortion of the waveform of E_1 .

It is not obvious how the shape of a 'self-rectified' quench pulse (Arndt 1949) could vary sufficiently with the applied h.t. voltage to cause the effect.

It was noticed that when the system was over-corrected

the apparent dead-time was less dependent on the x-ray h.t. voltage and the steady component of E_1 : the dead-time maintained a fairly steady negative value. In one case, a 10% increase in the h.t. voltage merely changed the apparent dead-time from -30 to -60 μ s. Presumably this occurred because the timing was confined to the central portion of the x-ray pulse, where the counting losses are relatively constant at a rate rather greater than that required for exact correction (Arndt 1949). A small and constant negative dead-time could be allowed for by feeding pulses from an auxiliary oscillator directly into the timing scaler (during the inactive half-cycle of E_3 only). This principle was tested successfully (in a simulated form) with the present circuit. The subject is discussed at greater length elsewhere (Trott 1959).

Acknowledgments

The author wishes to thank Dr. J. W. Hughes for his supervision during the research in the course of which the above work was carried out, and the Department of Scientific and Industrial Research for a maintenance allowance.

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New design of spectropolarimeter

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Abstract

A new design of spectropolarimeter is described, in which the functions of monochromator and polarimeter are combined by using two crystalline quartz prisms both to disperse the radiation and to polarize it. The two prisms are fixed in position, wavelength scanning being achieved by the rotation of two plane mirrors in unison about a common axis. The optical rotation of the specimen is compensated by means of a Faraday cell and is thus measured in terms of current. The present experimental design can be used over a wavelength range from 600 to 220 $m\mu$, the full-scale reading varying with wavelength, being equivalent to about 0.1° at 600 $m\mu$ and rising to about 1.1° at 220 $m\mu$. The output noise level is between

about 0.1 and 0.5% of the full-scale rotation over this spectral range.

Introduction

USEFUL information about optically active substances can often be obtained by studying their rotatory dispersion (see, for example, Djerassi, Foltz and Lippman 1955), and there has lately been considerable interest in spectropolarimeters designed to measure and record optical rotation as a function of wavelength. In the designs which have so far been proposed some kind of photoelectric polarimeter is combined with a conventional monochromator

(see, for example, Fordyce, Green and Parker 1958, Rudolph and Bruce 1959, and Billardon and Badoz 1959). Since it is desirable that the wavelength range of the instrument should extend as far as possible into the ultra-violet region, the polarizer and analyser are sometimes made of crystalline quartz rather than calcite, which begins to absorb strongly at about $240\text{ m}\mu$; this system is preceded by a monochromator with optics of quartz or fused silica.

The work described here was prompted by the consideration that if quartz optics are required, much could be gained in simplicity of design and construction, and hence in light transmission at the shorter wavelengths, if the functions of monochromator and polarimeter could be combined, and the same prisms used both to disperse the radiation and to polarize it. In principle, this can be accomplished by replacing the prisms of a conventional double monochromator with quartz prisms cut with the optic axis perpendicular to the ray path, so that each prism produces two spectra, laterally separated and polarized at right angles to each other. If the slits are arranged so that, at a particular wavelength, the first half of the monochromator passes the ordinary ray and the second half the extraordinary ray (or *vice versa*), then the light emerging from the final exit slit will contain only that wavelength; its intensity will depend on the relative orientation of the optic axes of the two prisms. In other words, the first prism acts as a polarizer and the second as an analyser, and a specimen may be examined for optical activity by placing it somewhere in the light path between the two prisms.

It is obviously impracticable with this arrangement to measure optical rotation by rotating the analyser with respect to the polarizer. However, a photoelectric polarimeter previously described (Gillham 1957, Gates 1958) uses a polarizer and an analyser which are fixed in the crossed position, the optical rotation of the specimen being compensated by means of a Faraday cell. To achieve this compensation automatically, a modulator placed between the polarizer and analyser oscillates the plane of vibration of the polarized light through a suitable half-shadow angle at some frequency in the audio range. As a result, any departure from the balance position results in a modulation of the emergent light intensity at the oscillation frequency; this modulation is detected by a photomultiplier, the a.c. output of which is amplified and used to control the d.c. current through the Faraday cell compensator. This principle is obviously well suited to a recording instrument, in that optical rotation is measured in terms of current. An experimental instrument has therefore been constructed, in which this principle is applied to the optical arrangement indicated above.

Design of spectropolarimeter

The optical system of the spectropolarimeter is shown in Fig. 1. The instrument is arranged to give additive dispersion and uses two 60° prisms, with faces approximately 4 cm in length and height, together with aluminized spherical mirrors of 50 cm focal length for collimating and focusing. The prisms, P_1 , P_2 , are fixed in position, and wavelength scanning is achieved by rotation of the two plane mirrors, X_1 and X_2 . Although the two prisms have effectively different refractive indices, one passing the ordinary ray and the other the extraordinary ray of the set wavelength, it was found possible, by using the prisms at slightly different angles of incidence, to obtain satisfactory tracking between 200 and $600\text{ m}\mu$, with the two mirrors rotating in unison about a common axis. The mechanical construction could thus be

simplified by mounting the two mirrors on a single table; this is at present rotated by means of a synchronous motor resulting in a non-linear wavelength scale.

It will be noted that the concave mirrors, C_1 and C_2 , the first half and C_3 and C_4 in the second half of the system are used off-axis in the arrangement, which produces some compensation of the extra-axial aberrations.

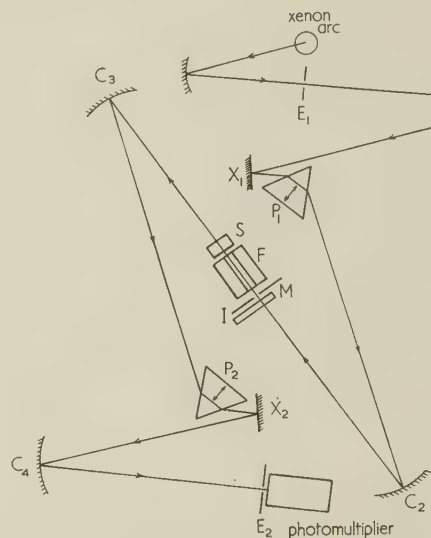


Fig. 1. Optical system of the spectropolarimeter (not to scale).

The polarimetric system requires a crossed polarizer and analyser, and the two prisms are therefore cut in the same way; in the present system the optic axis is perpendicular to the prism base. Theoretically there is a slight advantage in the optic axis being parallel to the refracting edge of the prism, although in practice this is probably not significant. The modulator M, specimen S and Faraday cell compensator F are all mounted close to the intermediate slit I, in order that their size may be kept to a minimum. The compensation consists of a solenoid of about 65 000 turns of 42 s.w.g. enamelled wire, wound around a core of synthetic fused silica, 1 cm in diameter and 5.7 cm in length. The coil has a resistance of $12\,500\ \Omega$, and at the normal maximum operating current of approximately 7 ma the Faraday cell produces an optical rotation of about 0.1° at $600\text{ m}\mu$, rising gradually with decreasing wavelength to about 1.1° at $220\text{ m}\mu$ (Fig. 2). In the visible and near ultra-violet regions, this rotation range could, of course, be increased simply by substituting a fused silica core of the Faraday cell compensator with a glass of higher Verdet constant. Although the full-scale rotation of the instrument is thus relatively low, it should be noted that in the study of anomalous rotatory dispersion, strong specimen absorption will often limit the maximum measurable rotation to this order of magnitude.

Two types of modulator have been used. The first, similar in principle to the system employed in a photoelectric polarimeter (Gillham 1957) consists of two pairs of quartz sector plates rotating so that each plate passes in turn through the light beam. The difference in thickness of these pairs of plates corresponds to an optical rotation of about 6° at $550\text{ m}\mu$; a compensating plate of the mean thickness, with optical activity of the opposite sign, ensures that the vibration plane of the polarized light is oscillated symmetrically (i.e. $\pm 3^\circ$) about the mean direction set by the polarizer. The unit rotates at 2000 rev/min; this results

oscillation of the vibration plane of about 67 c/s, ensuring the instrument is insensitive to 50 c/s pick-up. More recently, a Faraday cell modulator fed with alternating current has been used, similar in principle to that described by Gillham (1956) and Gates (1958). Since the Verdet

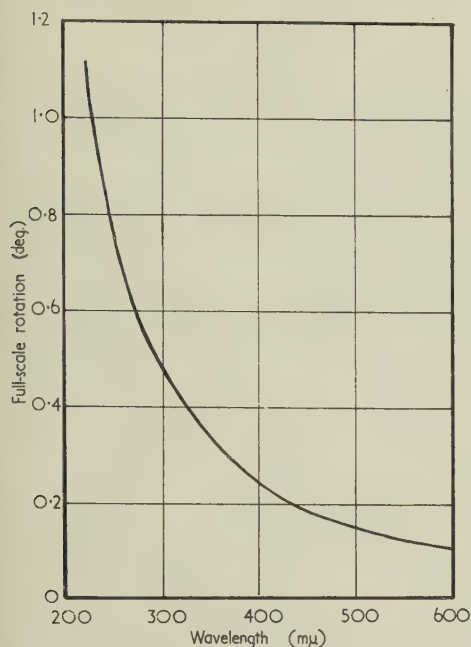


Fig. 2. Variation of full-scale rotation with wavelength.

constant of fused silica is relatively small, the solenoid has to dissipate an appreciable amount of electrical power in order to obtain an adequate half-shadow angle, necessitating the use of water cooling. The solenoid at present in use consists of eight turns of approximately 6 mm bore copper tubing, through which cooling water is circulated. With an input power of about 170 w, the half-shadow angle at a wavelength of 550 mμ is $\pm 1.8^\circ$, using a synthetic fused silica core 5.7 cm in length. The modulator is driven at a constant frequency without any significant pick-up trouble.

With both types of modulator the half-shadow angle gradually increases gradually at shorter wavelengths (i.e., according to the natural rotation of quartz for the sector disk, and to the Verdet constant of silica for the Faraday cell). In practice, the lower limit to this half-shadow angle is controlled by the effect of unpolarized or elliptically polarized light in the system, due to scattering or birefringence in the optical components. As the amount of radiation available in general, decrease at shorter wavelengths, this increasing half-shadow angle is a desirable feature.

The source of radiation is a 150 w xenon arc (Osram type D 162) run off a d.c. supply. The most intense part of the arc consists of a bright spot about 0.15 mm in diameter concentric to the cathode, and this has to be imaged on to the entrance slit in order to collect as much radiation as possible. The cathode spot tends to wander over the electrode surface, and this may result in local fluctuations in beam intensity at the aperture of the optical system. As the polarimetric measurement position is rather sensitive to such fluctuations (see above), it was found necessary to stabilize the position of the image by means of a servo-control on the orientation of the imaging mirror. This control is exercised by four

solenoids acting on the mirror against spring restraints, and the required error signal is obtained by directing part of the light reflected from the mirror on to four germanium phototransistors, using a thin silica plate as beam-splitter. It should perhaps be noted that provided the highest spectral resolution is not required (i.e. an entrance slit width of 0.5 mm or larger is used), the instrument will perform quite adequately without any servo-control on the imaging mirror and the results shown in Fig. 3 (see below) were, in fact, obtained under such conditions.

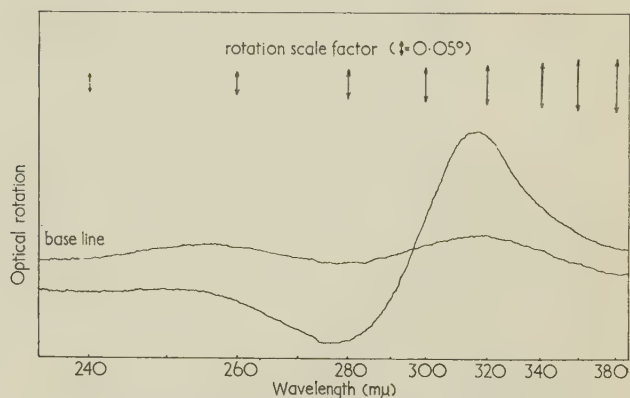


Fig. 3. Rotatory dispersion curve of androsterone, 1 cm path length: concentration approximately 0.64 mg/ml.

The electrical system is essentially the same as that previously described (Gillham 1957, Gates 1958), that is to say, the photomultiplier (E.M.I. type 6256B with fused silica window) is followed by an a.c. amplifier, a phase-sensitive detector switched in synchronism with the modulation signal, and a d.c. amplifier that feeds the Faraday cell compensator; the current through the compensator is measured by means of a potentiometric recorder. Since the amount of radiation available changes considerably with wavelength, the e.h.t. power supply to the photomultiplier is varied automatically by means of an automatic gain control system, which maintains a constant mean d.c. output from the photomultiplier. The relative amount of stray radiation is also wavelength-dependent (and may be appreciably increased due to an absorption band in the specimen) and an automatic gain control system maintaining a constant level of the modulated signal from the photomultiplier would therefore seem to be advantageous.

Operation and performance of the instrument

The overall performance of the instrument is illustrated in Figs. 3 and 4; Fig. 3 shows a record obtained with an 1 cm cell containing a solution of androsterone in methanol, at a concentration of approximately 0.64 mg/ml., together with the base line obtained with the solvent alone. This record was obtained with a constant slit-width, so that the spectral resolution varied with wavelength according to the dispersion of quartz, being about 1 mμ at a wavelength of 300 mμ; the recording time for each trace was about thirteen minutes. It will be noted that the base line trace is by no means flat, a factor which appears to be caused by the sector disk modulator and by birefringence in the compensator core. The variation of rotation scale factor with wavelength shown in Fig. 2 is illustrated again in this record by the arrowed lines, each of which corresponds to an angular rotation of 0.05° .

The record in Fig. 4, due to a sucrose solution of concentration 14 mg/ml., was obtained using the Faraday cell modulator and Faraday cell cores with no significant strain. It will be seen that the improvement in the shape of the base line trace is very marked. The usable wavelength range at present extends down to about 220 $m\mu$, being determined by

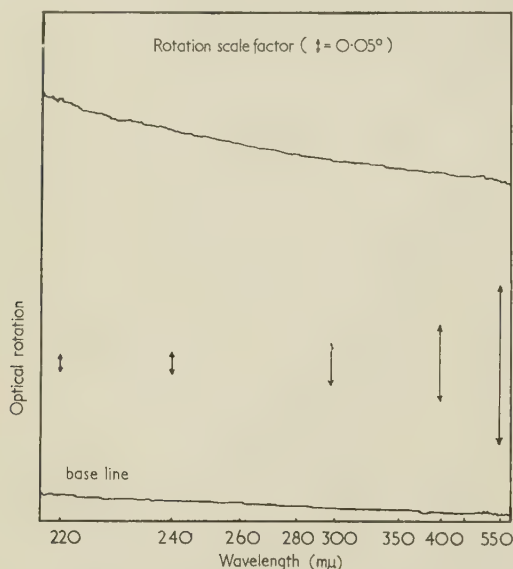


Fig. 4. Rotatory dispersion curve of sucrose, 1 cm path length: concentration approximately 14 mg/ml.

absorption in the crystalline quartz prisms; by using prisms of quartz with less ultra-violet absorption, it is hoped to extend the range down to 200 $m\mu$. Over most of the wavelength range, a specimen optical density of at least one can be tolerated.

The noise performance has not been investigated in great detail, since it depends on a number of factors, such as the spectral bandwidth and the light grasp of the optics, which are peculiar to this particular version of the instrument rather than to the design in general. However, recorder traces taken over periods of about ten minutes at various fixed wavelengths indicate a r.m.s. noise level of approximately 0.0004° at 550 $m\mu$ rising to about 0.001° at 250 $m\mu$ (i.e. between about 0.1 and 0.5% of the full-scale rotation). For these measurements, the spectral bandwidth was 1 to 2 $m\mu$, and the overall bandwidth of the recording system between 0.05 and 0.1 c/s. The noise level will, of course, be greater in the presence of strong specimen absorption.

It should be noted that for the potential accuracy of the instrument to be realized, great care must be taken to avoid significant, and probably varying, rotations being caused from birefringence effects occurring in sample cell windows and surface films.

The polarimetric balance position depends to some extent on the distribution of light intensity over the aperture of the beam. If, for example, the upper or lower half of one of the collimating mirrors is obscured, there is a change in the balance position of the order of 0.02° , although for obscuration of the left- or right-hand side, the change is only about one-twentieth of this. This variation is due to the effect of reflections at the two intermediate concave mirrors, C_2 and C_3 , situated in the light path between the polarizing and analysing prisms. It will be appreciated that, in this

respect, the system differs from the usual design of polarimeter with an almost collimated beam of light between the polarizing elements. The plane of incidence of a ray of light striking either of these two concave mirrors is not, in general, either parallel or perpendicular to its plane of vibration. Since the components vibrating parallel and perpendicular to the plane of incidence will have different reflection coefficients and the reflection will introduce some phase difference between them, reflection from the mirror will produce a small twist in the plane of vibration and also a small amount of elliptical polarization. The actions of the two mirrors in this respect are additive and the plane of vibration (or strictly, the major axis of the ellipse) thus varies from point to point of the cross section of the beam, with a distribution which is symmetrical about the horizontal diameter of the beam and unsymmetrical about the vertical diameter, since the mirrors are used off-axis. Thus, although the mean plane of vibration is unchanged provided the aperture is uniformly illuminated, any departure from this condition can affect the zero reading. Stabilization of the arc image ensures a constant illumination of the aperture of the instrument and thus contributes to the stability of the zero.

At the short wavelength limit of the instrument's range absorption in the quartz prisms will produce asymmetry in the intensity distribution, since the dispersion of the prism is additive. Fortunately, however, this effect is equivalent to obscuring one side of the collimating mirror, rather than the upper or lower part, so that the twist in the mean plane of vibration is small. In any case, the twist should be a constant and reproducible one, which will not affect the stability of the zero-reading. The disposition of the two concave mirrors, C_2 and C_3 , is such that the collimated beam incident upon the first mirror is parallel to that leaving the second. With the alternative arrangement of mirror symmetry about the intermediate slit (i.e. the collimated beam leaving C_3 in the direction of prism P_1), the two off-axis reflections produce a twist in the plane of vibration by a purely geometrical effect which is considerably greater than the twist due to the reflection coefficient effect referred to above. With the arrangement in Fig. 1, but with a slight mismatch of the off-axis angles, it is possible that the residual geometrical twist could produce some compensation of the reflection coefficient effect, reducing the overall variation of the vibration plane over the aperture.

With regard to the accuracy as distinct from the precision of measurement, the most likely source of systematic error is the presence, in the light emerging from the exit slit, of stray light of the wrong wavelength. In general, the monochromator is a double one, so that the amount of stray light should be small. However, at the intermediate slit there are superimposed two beams of different wavelengths and comparable intensity, and although only one of these can reach the exit slit by a direct optical path, a small amount of the other can reach it by scattering from the various optical surfaces in the second half of the monochromator. At the intermediate slit there will also be a beam of a third wavelength, which reaches the slit by scattering in the first half of the monochromator, and which can then, by virtue of its different plane of vibration, follow the same direct path through the second half of the monochromator as the beam of the desired wavelength. As a result, there are two wavelengths, one longer and one shorter than that at which the instrument is set, for which the monochromator is effectively single rather than double.

Fortunately, however, measurements show that most of the stray light at these two wavelengths is depolarized, and is therefore unaffected by the operation of the modulator.

has no influence on the polarimetric readings. Thus, though the performance of the instrument with regard to light is worst at these two wavelengths, it is still superior to that of a single monochromator followed by a polarimeter, and with the latter arrangement stray light from the monochromator is fully effective in its action on the polarimetric reading.

Conclusion

The experimental instrument described above demonstrates the possibilities of the combined monochromator and polarimeter arrangement, and also, what is important from a constructional point of view, the feasibility of using mirrors and a simple form of wavelength scan. The description has been confined to only one arrangement of the mirrors and prisms, and it should therefore be pointed out that the system would probably function quite satisfactorily with certain other arrangements of these components.

Further developments would include driving the modulator by an oscillator at a frequency asynchronous with the supply mains. The possibility might also be explored of using a single Faraday cell to act both as modulator and compensator. This would reduce the thickness of the silica plates, and hence the amount of birefringence, and also the chromatic aberration which results from using the cores in a convergent beam. It might be difficult, with a single low-voltage Faraday cell, to combine the d.c. and a.c. drive and provide sufficient direct current; it is therefore worth remarking that compensation can be achieved by using the second harmonic of the modulator a.c. drive, rather than d.c., and such an expedient might simplify the electrical design.

With regard to the variable rotation scale factor, the examples given above have illustrated how a sample with normal rotatory dispersion results in a recorded trace roughly parallel to the base line (Fig. 4), while the presence of any anomalous rotatory dispersion is shown up quite clearly as a departure from this (Fig. 3). If, however, this variable rotation factor is not considered a desirable feature, a constant rotation could be achieved by controlling the sensitivity of the drive from the wavelength drive. A similar type of control could also be exercised on the amplitude of the modulator drive, in order to ensure the optimum half-wave angle over the whole wavelength range. The slit width (of E_1 and E_2 , Fig. 1) could also be varied automatically in order to maintain a constant spectral resolution. A possible alternative arrangement of controlling the slit width to maintain a constant photomultiplier signal would not seem to be undesirable, as the polarimetric zero varies slightly with the width of the slit; consequently the effects on the traces with and without the specimen could be somewhat different for the wavelengths at which the sample absorption was appreciable.

The accurate calibration of the optical rotation scale

through the spectrum does present certain problems. The varying sensitivity of the Faraday cell compensator with wavelength should, of course, be proportional to the Verdet constant of fused silica. Thus the present calibration curve (Fig. 2) was obtained from the Verdet constant values due to Sivaramakrishnan (1956), using his derived formula to extend the values to wavelengths shorter than those of his actual measurements. Absolute calibration at one wavelength (546 m μ) was achieved by measuring the same specimen on the spectropolarimeter and also on a photoelectric polarimeter (Gillham 1957) with an accurate divided head. This rather indirect calibration procedure is clearly not completely satisfactory.

In a system consisting of separate monochromator and polarimeter, the variation of scale factor with wavelength can be determined quite simply by recording traces through the spectrum at various fixed positions of the analyser; the difference between any two traces will then correspond to a certain constant angle. However, in the present integrated design of spectropolarimeter, rotation of the analysing prism produces a vertical movement of the spectrum imaged at the exit slit, and the accuracy of the calibration so obtained is therefore in some doubt. Ideally some arrangement which by a mechanical rotation could produce a known twist of the vibration plane is required. Work on the accurate calibration of the instrument is at present in progress.

Acknowledgments

Acknowledgment is due to Mr. N. O. Young and the Instrument Division of Ericsson Telephones Ltd., for the Faraday cell modulator and the servo-control system for stabilization of the arc image position. The work described here forms part of the research programme of the National Physical Laboratory, and this paper is published by permission of the Director of the Laboratory. The spectropolarimeter is the subject of a patent application.

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Modified design for ion-source canals

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Abstract

The possibility of replacing the orthodox cylindrical ion-source canal by a series of diaphragms is considered and some advantages of this modification are described.

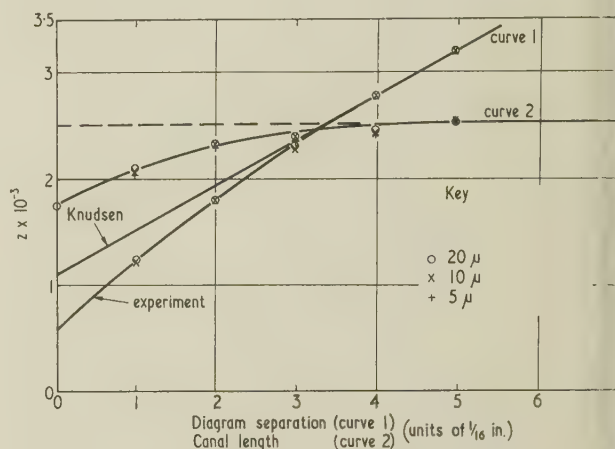
THE design of an ion-source canal is very often a compromise between the desire for a high impedance to gas flow and the need for a short, large-bore canal to enable large ion currents to be extracted. Considerable attention has been paid to the design of such canals and it has even been proposed that a canal with a stepped bore (Blanc and Degeilh 1959, Reifenschweiler 1954) be used to increase the impedance to gas flow without appreciably reducing the extracted current.

It is interesting to consider, in connection with the above requirements, the well-known Knudsen-Langmuir formula for gas flow through a cylindrical tube at reduced pressures. This shows that the impedance of a tube consists of the sum of two impedances, one due to the length and the other to the exit end of the tube, and it may be seen that if the tube is short the effect of the end may be of the same order as that of the cylindrical portion. This implies that a series of diaphragms having central cylindrical holes of length approximately equal to their diameter may be mounted coaxially with small separations and have an impedance equal to that of a cylindrical canal of the same bore and overall length. The Knudsen formula can, however, only be applied with certainty providing the length is very much greater than the diameter and the exit end of the tube opens into a large chamber.

To investigate the impedance of such diaphragm assemblies for which the Knudsen formula cannot be expected to give accurate results, a simple gas-flow apparatus was constructed, this enabled a series of diaphragms 1/16 in. thick and having 1/8 in. diameter central holes to be mounted with any desired spacing, and the total impedance measured. The results of these tests are given in the Figure and show the variation of impedance with canal length obtained by stacking the diaphragms in contact and also the variation of impedance of two diaphragms as the separation between them is increased.

From these results the impedance of any assembly of these diaphragms can be calculated. We assume that the last diaphragm in an assembly has the full impedance of an isolated one and that the end effect of each earlier one is modified by the presence of the diaphragm following it. To confirm this, we may compare the experimentally measured impedances for two particular assemblies with values calculated in this way. Firstly, consider three diaphragms with 1/8 in. separations. From the Figure, the impedance of a single diaphragm is 1.23×10^{-3} and the impedance of two diaphragms with 1/8 in. separation is 2.31×10^{-3} . Therefore,

the impedance of each of the first two diaphragms of assembly is given by subtraction as 1.07×10^{-3} . Hence calculated total impedance Z of the assembly is 3.39×10^{-3} . Direct measurement gives Z to be 3.5×10^{-3} . Secondly consider four diaphragms mounted with 1/16 in. separation. Calculation gives Z to be 3.78×10^{-3} , and, by di



Variation of impedance, curve 1—with canal length, curve 2—with diaphragm separation — — twice impedance of one diaphragm.

measurement, Z equals 3.81×10^{-3} . Thus results may be calculated correct to a few per cent. It is interesting to compare the impedance of these two assemblies with that of a canal of the same bore and length. For a canal of 1/8 in. bore and 7/16 in. long, Z is equal to 3.99×10^{-3} and therefore the two assemblies considered have 88% and 95.5% of the impedance of the continuous canal.

Thus it is possible to replace the normal cylindrical canal of an ion source by a series of diaphragms and retain virtually the same total impedance. It may be desirable to do this as either the spaces between the diaphragms may be used for differential pumping or the diaphragms may have different sized apertures in order to achieve simply the stepped canal mentioned earlier. It also provides a very flexible experimental arrangement and the diaphragms may be at different potentials to achieve focusing (Reifenschweiler 1954) in the canal.

There may, in fact, be a considerable gain in extracted current possible by use of a diaphragm canal and we are preparing to test this possibility experimentally. This possibility is shown by the work of Thonemann and Harrison (1954). The ion source described in this work has a very short canal but photographs of the beam profile lead one to expect that the canal length could be considerably increased with reduction of the extracted beam. They found experimentally

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ever, that this was not the case, the extracted current ng to approximately 20% of its initial value when the al length was increased from 2 to 6 times the radius. If effect is due in some manner to the proximity of metal he ion beam or to the high pressure region in a long al it should be possible, using diaphragms, to achieve a siderable improvement.

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Automatic recording dilatometer

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Abstract

The dilatometer described here enables changes in volume in time to be followed automatically and with high precision. Thus chemical reaction rates can be obtained directly without the need for graphical differentiation.

Introduction

DILATOMETRIC techniques are used frequently to investigate chemical reactions which involve volume changes (e.g. polymerization reactions). The apparatus here described enables volume changes to be followed automatically and with high precision as a function of time, that reaction rates can be obtained directly without the need for graphical differentiation. The dilatometer is based on that designed by Burnett (1950), modified by the inclusion of an extra tap to facilitate filling; the reactants are confined in a bulb by mercury and the volume changes are magnified by precision-bore capillary tubing.

Fig. 1 shows a schematic diagram of the complete apparatus. A length of rigid piano wire fits into the capillary of the dilatometer and is attached to a nut which runs on a high-tension screw thread. This nut is prevented from rotating by guides (not shown). The screw is driven via a universal coupling (the Meccano type is suitable) by means of a rotary solenoid (N. S. F. Ledex) which enables the screw to be turned round a quarter, half or complete turn at a time, a suitable circuit to permit this being shown in Fig. 2.

The operation is as follows, a reaction which causes volume contraction being considered (by reversing the direction of rotation of the screw an increase in volume can be followed analogously). The wire is first adjusted so that it is just making contact with the mercury in the capillary. As the reaction proceeds, the mercury in the capillary will fall and break contact. With the wire and mercury connected to an electronic relay, the latter becomes energized and the contacts in the solenoid circuit are closed. The solenoid thus energized commences to rotate and to drive the wire back into the mercury, thus opening contacts CD, but the circuitry

is such that the wire continues to be driven into the mercury until the solenoid completes one revolution (for simplicity we will only consider complete turns, but the sequence of events is similar for the quarter and half turns).

During rotation of the solenoid, the wiper on the second switch-bank makes momentary contact with one of the fixed contacts, completing the circuit to the time-recording device (in the simplest case, a solenoid-operated pen which marks

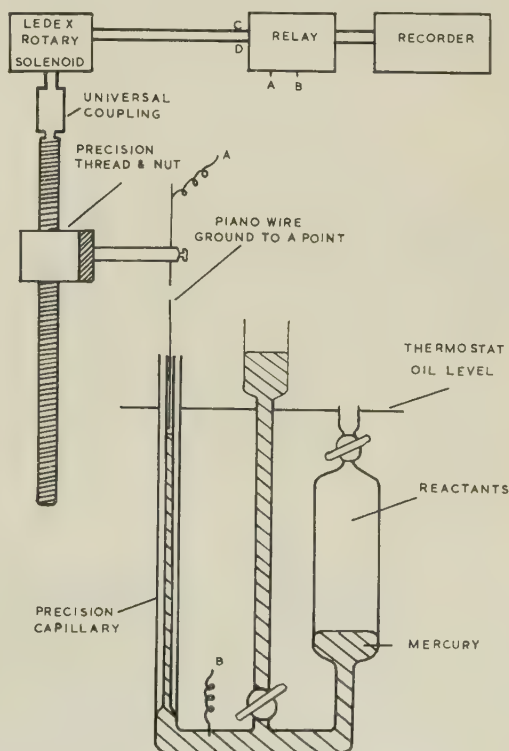


Fig. 1. Schematic diagram of apparatus.

a moving strip of paper). Nothing further happens until the mercury again falls and breaks contact with the wire, when the whole sequence is repeated. Since each turn of the screw thread corresponds to a small but constant volume

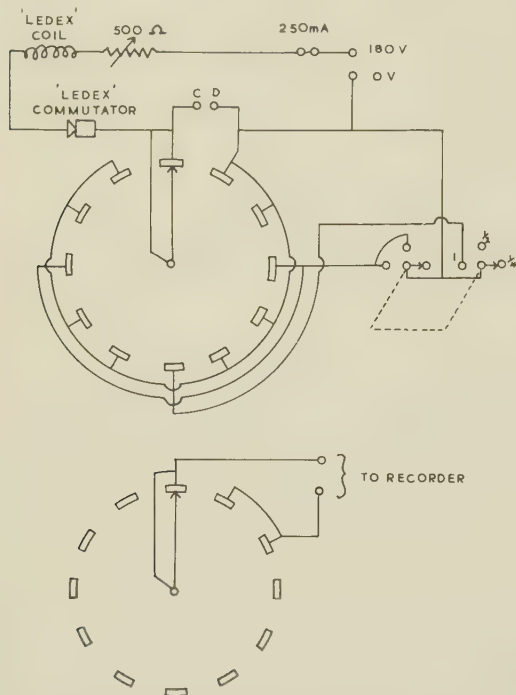


Fig. 2. Circuit diagram for rotary solenoid.

change, the time interval between each revolution corresponds to the time taken for this volume change to occur. If these individual changes are made small compared with the

total volume change of the reaction (by using a narrow capillary and/or a fine pitched thread), then to a good approximation the ratio of volume change to the time for such a change is equal to the rate of the reaction at that point. Thus, a plot of reciprocal time intervals against the number of solenoid revolutions is equivalent to a plot of reaction rate against extent of reaction.

The main source of error arises from variations in the shape of the mercury meniscus which must be kept thoroughly clean and free from grease. The tip of the wire (which is ground to a sharp point) is centred in the capillary by means of a bush which is an easy sliding fit in the capillary. If the wire is driven too far into the mercury each time, small globules of mercury are liable to be isolated from the main thread. This can be prevented by wiring the solenoid to give only quarter or half turns at a time. Since each quarter turn may not drive the wire down the same amount (because of cyclic errors in the screw and a small angular error in the positioning of the solenoid) it is often more satisfactory to record only the times between each complete revolution.

The accuracy of this apparatus is such that, using 50 mm³ of liquid and a capillary of 1.5 mm diameter, volume changes of the order of 1 part in 30 000 can be measured to an accuracy of 1–2%. To achieve such figures, extremely good thermostatic control is required (of the order of $\pm 10^{-3}$ °C).

The basic principle of the apparatus has been adapted by Dunn and Scanlan (1960a) to operate a stress relaxometer and to follow gas absorption (1960b).

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Automatic apparatus for measurement of the rate of absorption or evolution of gas

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Abstract

An apparatus is described in which constant pressure is maintained as gas is absorbed or evolved by changing that volume of a threaded rod which is inside the apparatus. The change in volume of the gas is then equal to the change in volume of the rod inside the apparatus. Use of an escapement to turn the screw through constant-volume increments provides a simple method of automation.

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Introduction

MANY investigations have been made into the determination of organic compounds by measurement of the rate of oxygen absorption at moderate temperatures (Bolland 1949) using an apparatus based on a constant-pressure gas burette (Bolland 1946). Considerable skill in the operation of such an apparatus is necessary in order that accurate rate measurements may be made.

A simpler, but equally accurate, method of measuring gas absorption or evolution by as little as 0.05 g substrate

been devised using an apparatus which can readily be made automatic and self-recording. In this method, compensation for the volume of gas absorbed or evolved by the substrate is provided by the change in that part of the volume of a threaded rod which is screwed through a suitable chamber sealed into the apparatus. Adjustments of the rod may be made automatically by use of an escapement device similar to that employed by Bell (1961) in a self-recording manometer.

Construction of the apparatus

The apparatus in the form suitable for following gas absorption is illustrated in Fig. 1. If the two arms of the manometer M are separated by closure of the tap T_2 , changes

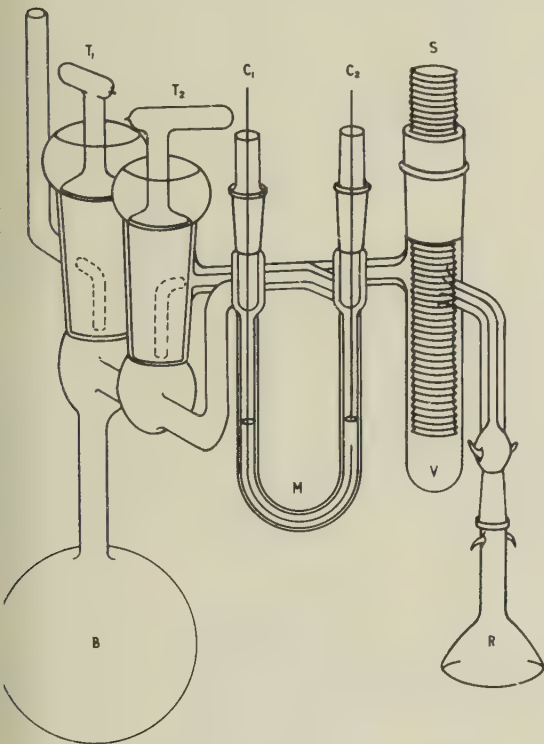


Fig. 1. Diagram of gas-absorption apparatus.

in pressure resulting from absorption of gas cause appropriate movements of the liquid in M. The pressure on the other side of the manometer remote from the substrate is kept constant by inclusion of a 50 ml. buffer volume B which compensates for the changes in pressure caused by the movement of the liquid in M. The apparatus may be operated manually using silicone oil as the manometric liquid, but for automatic operation, this is replaced by ethylene glycol saturated with sodium nitrite which has sufficient electrical conductivity for an electronic relay (supplied by Labgear Ltd.) to be operated through completion of a circuit when the liquid reaches platinum contact. On energization of the relay, the screw S is rotated by a small rotary solenoid (N.S.F. Ltd.) so wired that it can rotate only in one of the twelve positions at intervals of 30° . The 12 positions are normally available (Bell 1961). Thus momentary contact of the liquid with C_2 causes the screw to make one complete turn in the course of which the pressure rises sufficiently for the circuit through C_2 to be broken.

By means of an additional switch wafer on the Ledex rotary solenoid, the act of turning the screw serves to actuate an operations recorder. The timing device employed (IVO of Radiatron Ltd.) prints the time elapsing between successive operations of the Ledex.

Screws of $\frac{7}{16}$ in. diameter with 26 turns per inch and of $\frac{1}{4}$ in. diameter with 40 turns per inch have been used successfully, the finer thread enabling a smaller amount of substrate to be used. Threads made with tap and die and lightly greased with silicone grease were, when sealed with mercury, capable of holding a vacuum even while being slowly turned. Thus the chance of leakage under the small pressure difference arising during measurements of oxidation at about atmospheric pressure is negligible. The threaded nut is turned on the outside to the standard 1 in 10 taper and fits into a ground-glass cone on the apparatus, the joint being rendered gastight by application of silicone grease and clamped to prevent rotation. The mercury well, necessary to seal the screw, is integral with the nut.

Liquid substrates are contained in the vessel R, and agitation is produced by a small magnetic stirrer. Solid substrates, for example films of rubber, may be placed in the tube V into which the screw is admitted, in which case R may be dispensed with. Maximum sensitivity requires that the volume of the apparatus associated with the reaction vessel should be as small as possible; where indicated, therefore, the tubing is of 2 mm bore, and tube V is just large enough to contain the screw S, and if necessary, the solid substrate. Use of tubing of smaller bore would produce only a small decrease in volume and might introduce delay in the manometer response.

The entire apparatus fits inside a small thermostat bath and, therefore, the temperature throughout can be very carefully controlled. The apparatus may be evacuated, and oxygen admitted through tap T_1 . Provided the substrate is sufficiently involatile, the apparatus is evacuated, lowered into the thermostat bath and allowed to attain the temperature of the bath before oxygen is admitted. The apparatus is then brought into operation by closing both taps T_1 and T_2 .

Calibration of the screw

The lightly greased screw was calibrated by sealing the threaded nut into a glass joint at the end of a horizontal

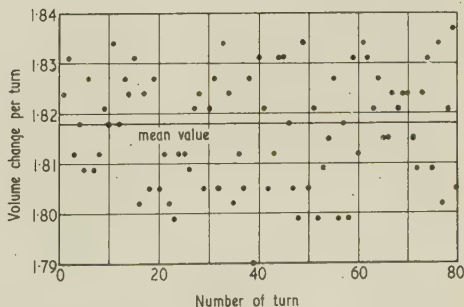


Fig. 2. Calibration of volume change resulting from one rotation of the screw.

precision-bore capillary. The apparatus was filled with distilled water and the movement of the liquid measured for each turn of the screw. The results for the $\frac{1}{4}$ in. diameter screw are shown in Fig. 2; the mean value obtained of the volume for one turn was 1.818×10^{-2} ml. with a standard

deviation of individual measurements of 0.011×10^{-2} ml. There is no trend in the values obtained along the length of the screw. A calculation of the volume from the profile of a Whitworth thread gave the volume per turn as 1.768×10^{-2} ml.

Test of the apparatus

The results obtained during oxidation of ethyl linoleate at 60°C are shown in Fig. 3 plotted as rate against extent.

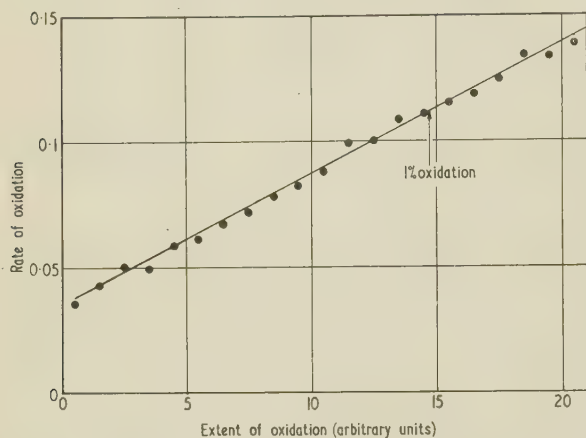


Fig. 3. Graph of rate of oxidation against extent of oxidation for ethyl linoleate.

In view of the large number of individual screw turns observed, the turns have been grouped in fours so that each point corresponds to the absorption of approximately 0.07 ml. oxygen. As previously observed (Bolland 1949) the rate increases linearly with extent.

The oxidation of samples of squalene from the same batch has been examined by Dr. P. W. Allen both in an apparatus of the type described here and in an apparatus of the type described by Bolland (1949). Identical graphs of rate against extent (Fig. 4) were obtained for two automatic measurements and for the visual measurements.

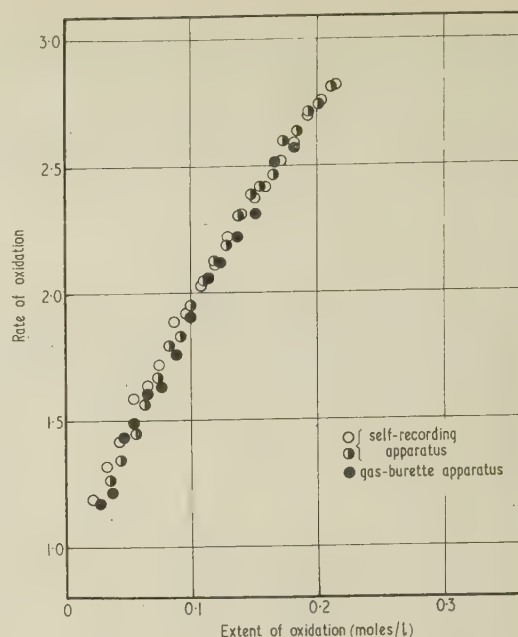


Fig. 4. Graph of rate of oxidation against extent of oxidation for squalene, obtained using both the automatic apparatus described above and the gas burette apparatus described by Bolland (1949).

Acknowledgments

The authors wish to thank Dr. P. W. Allen for permission to use the data shown in Fig. 4. The work forms part of a programme of fundamental research undertaken by board of the Natural Rubber Producers' Research Association.

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A pumpless circulator and Geiger-counter holder

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Note first received 10th August and in final form 29th September 1960

The course of an investigation of factors influencing the accumulation of radioactive isotopes by marine algae, it was necessary to determine the activity absorbed by algal sections at various times over periods of some days. For the production of reliable results it was essential to ensure vigorous and continuous circulation of the sea water containing the isotope being studied. Illumination and anoxia were also known to affect the accumulation of radio-isotopes by the sections and the apparatus had to be designed to facilitate the imposition of these conditions. The form of the apparatus finally evolved is illustrated in the diagram.

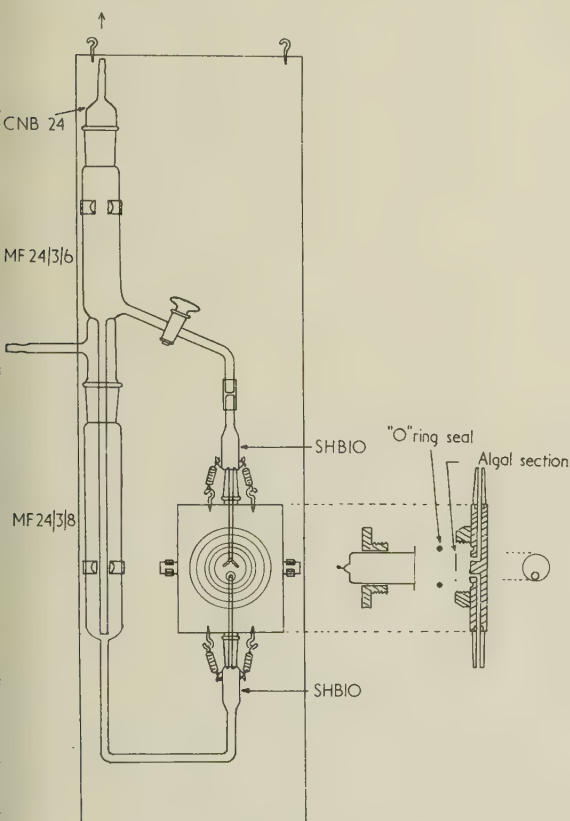


Illustration of apparatus.

The upper and lower containers of the circulator are made from standard test-tubes (Quickfit and Quartz, 4/3/6 and MF24/3/8 respectively) the remaining parts being based on standard joints (Quickfit and Quartz, CNB24 and SHB10). The Geiger-counter holder is fabricated from aluminium and rod Perspex. For ease of handling, the complete assembly is mounted on a 24 in. $\times$ 7 in. $\times$ $\frac{1}{4}$ in. Perspex panel. Terry clips the positions of which permit strain-free mounting of the glassware despite small variations in size. The strain in the circulating loop is obviated by incorporating a joint formed by a piece of plastic tubing.

The exploded view of the section holder shows the location of the algal section beneath the window of the Geiger-counter in the cavity formed by the 'O' ring seal. The section, which is cut by two sizes of cork borer, is specially shaped to ensure circulation of liquid over both its faces and its unique positioning in the holder. As the section would tend to function as a flap valve during the initiation of circulation, the uppermost feed-pipe to the cavity is terminated in two channels cut by an engraving tool.

After assembly of the counter holder (the remaining parts of the circulator are not dismantled between experiments), 50 ml. of sea water are added by removal of the uppermost joint and nearly fill the lower test-tube. By closure of the tap at this stage, the sea water may be prevented temporarily from reaching the algal section. If the tap is now opened and suction is applied at the top of the circulator or compressed gas at the side tube, liquid rises from the lower to the upper test-tube both directly via the vertical tube and indirectly via the section holder until no more liquid is available in the lower test-tube. The vertical tube now acquires a mixture of gas and liquid. The circulating loop is thus unbalanced and liquid flows rapidly from the upper to the lower container via the section holder. The rate of circulation depends on the pressure difference round the loop which in turn depends on the height of the vertical tube and its ratio of air to liquid. If this ratio increases, the return flow of liquid is accelerated and the constancy of composition of the air/liquid mixture tends to be maintained. In consequence of this self-regulatory property, the circulator functions satisfactorily over a wide range of gas pressures and with such small gas flows that ten circulators can readily be operated from one water pump. If the circulating liquid requires to be maintained below room temperature, heat may be removed by immersion of the lower loop in a refrigerated tank.

On completion of an experiment, liquid may be removed from the side arm by tilting the entire circulator.

The apparatus utilises a Geiger-counter (General Electric Co., type GM4) with an aluminium end-window which is protected from corrosion by sea water by two coats of self-curing epoxy-resin paint. In some cases the Geiger tube and holder can be operated as a liquid flow counter, the absorbing plant tissue being immersed in the upper container.

The development of this circulator forms part of a research sponsored by the United Kingdom Atomic Energy Authority whose permission to publish is gratefully acknowledged. The assistance of Mr. J. Tait in constructing the counter holders is also acknowledged.

Simple ultrasonic interferometer for student use

by L. MOLYNEUX, B.Sc., Ph.D., Physics Department,
University of Durham, Newcastle upon Tyne

Note received 12th September 1960

Most of the difficulties of setting-up and operating an ultrasonic interferometer are associated with mounting the quartz crystal and, while their solution provides useful research experience, they appreciably hinder the student's understanding of this elegant device (Pierce 1925).

Certain commercial quartz crystals (a frequency of 465 kc/s is suitable) consist of a bar of quartz vibrating longitudinally and mounted by fine wires welded to nodal points. Though

the end area of these crystals is small (about 1 mm^2), they can nevertheless be used in the mounting provided by the manufacturer as part of an interferometer. To complete the interferometer, some means of moving and determining the position of a reflecting surface must be provided. As the crystal is small this may conveniently be done by using a standard micrometer (Fig. 1), which need not be modified in

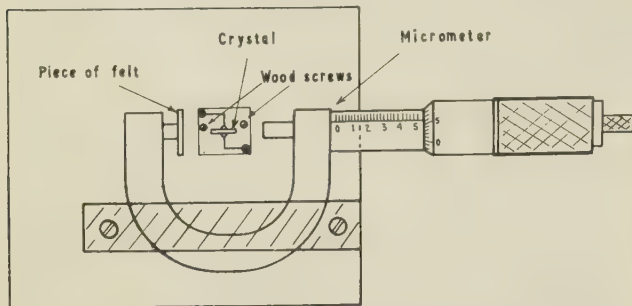


Fig. 1. The micrometer shown clamped to a baseboard, with the crystal (in the manufacturer's mounting) fixed to the board so that its long axis is coincident with that of the micrometer plunger. (The micrometer frame should be connected to the earth line.)

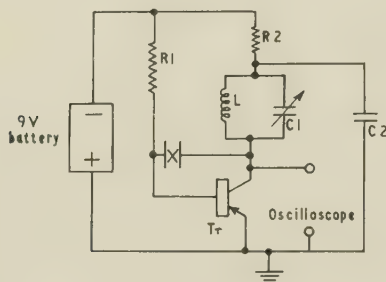


Fig. 2. Circuit of ultrasonic interferometer.

$R1 = 1.2 \text{ M}\Omega$
 $R2 = 2.2 \text{ k}\Omega$
 $C1 = 0.0005 \text{ }\mu\text{F}$
 $C2 = 0.01 \text{ }\mu\text{F}$
 $Tr = \text{OC45 transistor (Mullard Ltd.)}$
 $L = 450 \text{ }\mu\text{H.}$

any way. A transistor is used for the electronic circuit (Fig. 2), and needs only a single 9 v battery to supply the power. Though several methods of detecting the acoustic damping of the crystal are possible, a simple and instructive way is to display the collector waveform of the transistor on a cathode-ray oscilloscope. The velocity of sound is then measured by observing the readings of the micrometer for successive minima of this waveform.

The device may be used as it is to measure the velocity of sound in room air or, if the micrometer plunger and crystal are enclosed, the velocity of sound in other gases.

REFERENCE

PIERCE, G. W., 1925, *Proc. Amer. Acad. Sci.*, **60**, 271.

Low-capacitance electrometer earthing key

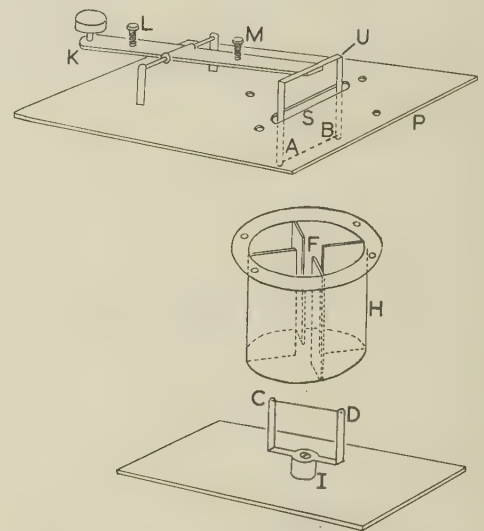
by L. A. W. KEMP, B.Sc., Ph.D., F.Inst.P., Physics Department, The London Hospital Research Laboratories, Ashfield Street, London, E.1

Note received 12th September 1960

In many electrometer systems it is necessary to employ an earthing key highly insulated on one side, and in which the inter-contact capacitance rapidly assumes very low values

after separation of the contacts. Spurious indication (brought about by the change in capacitance to earth of the electrometer system, as the gap between the contacts widens) may otherwise be obtained immediately after opening the key. The capacitance to earth of many electrometer systems is itself often very low (of the order of a few picofarads only), and it is desirable that the inter-contact key capacitance should fall rapidly to a value ten to one hundred times smaller than this after the key has opened.

A key has been designed fulfilling this condition. It operates satisfactorily, for example, as the grid earthing key in an electrometer system employing a sub-miniature electrometer valve. An exploded view of the key is shown in



Exploded view of electrometer earthing key.

Figure; K is a conventional key lever, which carries a small metal U-bracket U at the end. This bracket passes through a slot S in the metal baseplate P of the key (this plate serves to screen off the key lever, which is the main moving part) and carries between its lower ends AB a fine platinum wire 0.006 in. in diameter. The U-bracket is of beryllium copper, and is sprung so as to keep the platinum wire under correct tension. Opposite the wire AB, and at right angles to it, is another similar wire CD fixed in exactly the same manner to a second U-bracket, which is mounted on an amber insulator I inside the electrometer valve compartment. This lower U-bracket is connected to the grid of the electrometer valve. The two crossed wires AB and CD complete the key contacts, and, intrinsically, provide a very low inter-contact capacitance. The latter cannot be fully realized, however, unless the two U-brackets carrying the wires are effectively screened from each other. This screening has been achieved quite simply by mounting on the under-side of the baseplate P a cylindrical metal 'hood' H, inside which are four metal fins F which divide the cylindrical space into four quadrants, the gaps between diametrically opposite pairs of fins being about $\frac{1}{8} \text{ in.}$ Thus the inter-contact capacitance is reduced to that which exists between two $\frac{1}{8} \text{ in.}$ long wires 0.006 in. diameter, at right angles to each other. The screws L and M mounted above the key lever enable the contact pressure between the wires, and the maximum capacitance after opening the key, to be adjusted to a nicety.

A new model of the portable ionization comparator

described previously (Kemp and Banfield 1957), has been modified to incorporate this key, and the sensitivity and stability of balance has thereby been considerably enhanced.

REFERENCE

P. L. A. W., and BANFIELD, B. J., 1957, *J. Sci. Instrum.*, **36**, 27.

Thermoelectrically cooled probe for the determination of semiconductor type

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The Mullard Radio Valve Co. Ltd., Electronic Component Division, Mitcham Junction, Surrey

Note received 16th September 1960

A convenient method for the determination of semiconductor type is by determining the sign of the thermally generated e.m.f. arising when a probe of different temperature is placed in contact with the sample (Fig. 1). In the conventional

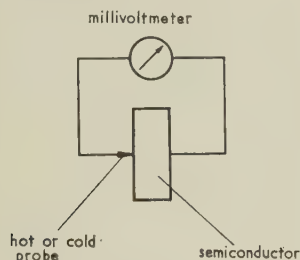


Fig. 1. Position of probe for type detection.

method the probe is made hot relative to the sample and thermally generated carriers are injected into the semiconductor from the probe. In the case of germanium, one difficulty is that, in a near-intrinsic sample, the heat from the probe tends to transfer to the germanium, and to diffuse it into the intrinsic region. This will cause a high resistivity p-type sample to appear as n-type using a conventional hot-probe. Conversely, however, if the probe is at a lower temperature than the bulk sample, then the type inversion cannot occur and results are now unambiguous.

To determine type using a hot probe, the probe is made positive and a forward reading on a millivoltmeter indicates p-type, and *vice versa*. In the case of a cold probe, the probe is made negative and a forward reading again indicates n-type.

Two pairs of bismuth-telluride junctions connected in series in a cube form the basis of the cooling device (Fig. 2).

The bismuth-telluride sections were 5 mm square by 10 mm long. The electrical connections were 18-gauge copper sheet, as were the heat dissipation and absorption fins. Electrical insulation was by thin mica layers coated with silicone grease, the assembly being clamped together with nylon screws. The power requirements of 9 A at 0.5 V were supplied from a transistor power supply.

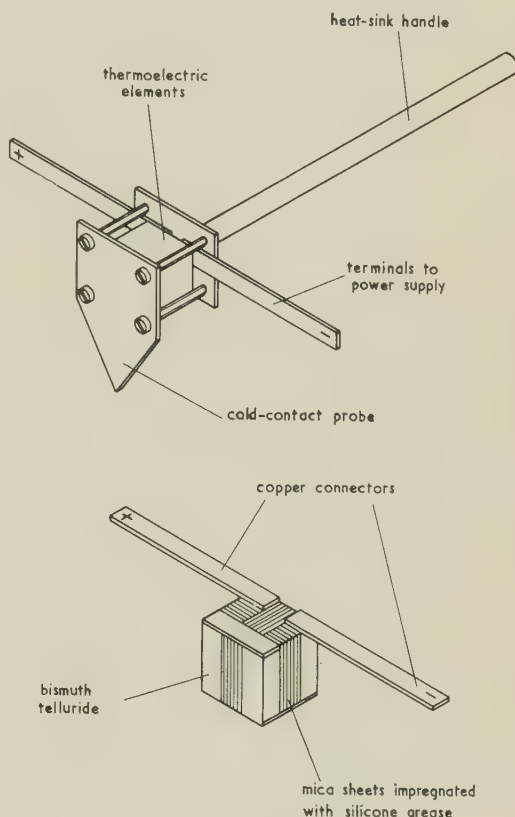


Fig. 2. Cooling device.

Without any thermal lagging of the active elements, the probe tip was lowered in temperature by about 11 deg. C. This was quite sufficient to give an easily detectable e.m.f. A Weston millivoltmeter was used as detector, but a centre-zero meter would be more convenient, giving direct reading of p- or n-type according to the direction of deflection. This would be particularly valuable for junction detection.

The authors wish to express their thanks to the Directors of The Mullard Radio Valve Co. Ltd., for permission to publish this note.

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep her informed of their new or improved products. The Institute of Physics and The Physical Society assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

Transistor test set type 156. Microcell Limited, Electronics Division, Blackwater Industrial Estate, Camberley, Surrey.

This test set is designed to measure the parameters of p-n-p and n-p-n transistors. Parameters which can be measured are amplification factor β , cut-off frequency $f\beta_{co}$, collector leakage I'_{co} , and collector turnover voltage V_t of transistors (grounded emitter configuration) and V_t and I_{co} of diodes.

The instrument incorporates a differential input, wide-band valve voltmeter as a β indicator and a wide-band oscillator as a signal source. The oscillator covers the range 1 kc/s–10 Mc/s; it produces a stable output within 0–1 dB over this range. The response of the valve-voltmeter is within about 1 dB from 1 kc/s to 10 Mc/s. A bridge-type control circuit minimizes output variation with changes in ambient temperature. Collector supplies are 2–10 v at 3 A and 0–10 and 0–100 at 30 mA.

Collector voltage and collector current are monitored on edge-type meters stacked one above the other so that both may be read simultaneously. All meters are fully protected against overload. Provision is made for external monitoring of the base current. Measurement ranges are: β , 8–200 in two ranges; collector current I_{co} , 300 μ A–3 A in four ranges; collector turnover voltage up to 100 v.

Dielectric test set type 160. Microcell Ltd., Electronics Division, Blackwater Industrial Estate, Camberley, Surrey.

Operating over a frequency range from 8800 Mc/s to 9750 Mc/s, this test set measures dielectric constants up to 10 and loss tangents from 0.008 upwards in the temperature range 20°C to 450°C. The design is based on a 'Magic-T' waveguide configuration; energy is fed into one arm from the klystron oscillator via an attenuator, the opposite arm being terminated in a crystal detector. The remaining two arms are terminated in the one case by the sample holder enclosed in its oven, and in the other case by a calibrated variable short circuit of the plunger-type. Initially the Magic-T is balanced by positioning the short circuit to produce minimum crystal output—usually indicated on a selective amplifier—and the plunger position is noted. The sample is then introduced and brought up to temperature and the change in plunger position required to re-balance the Magic-T is a measure of the electrical length of the sample from which the curves supplied enable the dielectric constant to be calculated. Loss tangent is obtained from the difference in amplitude of the reflected waves due to loss in the sample.

Accuracy is of the order of 3% for dielectric constant and 5% for loss tangent.

Transistor R.C. oscillators, types TG150 and TG150M Levell Electronics Ltd., 10–12 St. Albans Road, Barmouth, W. Herts.

These R–C oscillators use transistors as the active component with the advantage of freedom from many of the defects which exist in comparable valve oscillators. The much lower power consumption of the transistor results in the elimination of slow drifts of frequency and amplitude that are characteristic of valve oscillators during the warm-up period. The low power consumption also permits long life batteries to be used as the supply with the complete elimination of harmonic modulation.

The circuit of the oscillator comprises a transistor amplifier with positive feedback applied via a Wien bridge select network and negative feedback applied via a thermistor amplitude stabilizing network. Type TG150M differs from type TG150 by the addition of an output meter.

The resonant frequency of the Wien bridge network is continuously variable over one decade by a calibrated frequency control. Five ranges are provided to give coverage from 1.5 c/s to 150 kc/s with an effective total scale length of 50 inches.

Two transistors are used in the output stage in a feedback linearized circuit such that the output of the oscillator is negligibly distorted although the supply current is 1 A. Accuracy is to $\pm(3\% + 0.15 \text{ c/s})$ and output is up to 2 V into 600 Ω .

Extrusion speed transmitter. Cambridge Instrument Co. Ltd., 13 Grosvenor Place, London, S.W.1.

The extrusion speed transmitter continuously measures the ram speed of hydraulic presses (or any other machine producing a linear or equivalent rotational movement that can be coupled to the transmitter). It converts this varying mechanical quantity into a proportional electric current which will operate a number of separate indicators and recorders.

The linear movement of the press is changed, by way of a tape and pulley, into a rotational movement of a shaft, and this is measured by a force–balance servo system. The current produced is of the order of 0.75 mA and is independent of line resistance up to 2000 ohms. The minimum range of a standard instrument is 10 mm per second.

Spra-Koat Zero Mist. Livingston Laboratories Ltd., Red Bank, Street, London N.19.

A product of the General Cement Manufacturing Co. of U.S.A., this is a highly volatile but non-inflammable liquid and is a useful aid in detecting faulty capacitors, resistors, soldered joints or transistors and in studying the effect of temperature changes on components. In use, Zero Mist is sprayed directly from its container on to the component under operating conditions and by rapid evaporation lowers the temperature of the component concerned, allowing immediate observation of any change in characteristics. It leaves no deposit and will not spill or evaporate from the convenient spray-type container in which it is supplied.

ical calibration goniometer for survey cameras. Hilger and Watts Ltd., 98 St. Pancras Way, Camden Road, London, N.W.1.

Vertical calibration goniometer for survey camera lenses have been introduced by Hilger and Watts to meet the demands for greater accuracy and closer calibration of distortion characteristics. Visual and photographic measurements can be made with the same instrument which is, in effect, a large dolite with the transit axis in the shape of a 'stirrup'. The lens unit, or the complete camera, is set up so that the vertical transit axis passes through the front node of the lens.

The telescope of the goniometer sights upwards from the centre of the stirrup and intersects the transit axis at 45° angles, enabling a graticule in the focal plane of the camera to be observed. A 6-inch glass circle with an optical reading system is fitted to one end of the axis and readings to second of arc are made by an optical micrometer. Maximum precision and ease of setting is assisted by a goniometer at the opposite end of the axis, the faces of which are read by a Hilger and Watts autocollimator with a precision of better than 1 second of arc. The goniometer rotates about a vertical axis to take measurements in any desired orientation.

For photographic calibration, the eyepiece of the telescope is replaced by a lamp and the graticule is projected on a sensitized plate in the focal plane of the camera. The instrument stands on a low metal tripod and the camera is mounted on a gantry fitted with a levelling platform.

Ultra-microtome. Cambridge Instrument Company Ltd., 13 Grosvenor Place, London, S.W.1.

Cambridge Instrument Company Ltd., have marketed an ultra-microtome which is a slightly modified version of an instrument designed by F. A. Huxley. It is purely mechanical in principle and is hand operated to avoid electrical vibrations from a motor drive. The operating arm is actuated by hand and, for the cutting stroke, allowed to fall under its own weight. The speed of fall is controlled by a governor in an oil-filled dashpot. During the return stroke the specimen is displaced to one side of the knife-edge and is advanced. The displacement and advance mechanism is completely disengaged during the cutting stroke. The specimen holder is designed for use with glass knives but it can also be used with diamond knives, etc. A binocular microscope is necessary for the examination of the cut sections and can be supplied if required. Automatic advance of the specimen can be made in steps of $5\text{ }\mu\text{m}$ from zero to $150\text{ }\mu\text{m}$. The area of cut section can be $3\text{ mm} \times 4\text{ mm}$ if needed.

Leakage tester, model 45C. Taylor Electrical Instruments Ltd., Montrose Avenue, Slough, Bucks.

This instrument is capable of testing over 5000 different types of valves, British, American and Continental. Two ranges of insulation conductance are provided $0\text{--}3\text{ mA/V}$ and $0\text{--}15\text{ mA/V}$, and tests are also incorporated for electrode short circuits, leakage and emission. A separate TV tube adaptor model 445 is available which now incorporates a special base for the latest wide angle 110° tubes. A feature of this new instrument is the incorporation of test facilities for checking the latest 12 volt car radio valves; 21 valve holders are incorporated.

'Speedivac' Penning type vacuum gauges, series 5. Edwards High Vacuum Ltd., Manor Royal, Crawley, Sussex.

These gauge heads have an improved electrode arrangement which eliminates the calibration discontinuities encountered in previous designs and ensures operation at very low pressures. The pressure range covered is 10^{-2} torr to 10^{-5} torr in two scales. The range can be extended to 10^{-6} torr by use of an external meter. Two types of gauge head are available:

The flange mounting metal head Model 5MF, in which the electrodes can easily be withdrawn for cleaning, and the glass head Model 5GH with $\frac{1}{2}$ in. (12.7 mm) bore borosilicate connection. The glass head can be baked to 450°C after removal of its outer cover and magnet assembly.

Each head is supplied calibrated for dry air and is complete with a calibration unit which enables any head to be used with any 'Speedivac' Model 5 Penning gauge control unit, thus permitting full interchangeability for maintenance purposes.

Transformation printers. Hilger and Watts Ltd., 98 St. Pancras Way, Camden Road, London, N.W.1.

Two versions of the Hilger and Watts transformation printer are now available for producing photogrammetric diapositive plates from air-survey negatives. In addition to the universal model SB 13, which produces enlarged or reduced diapositives as required, a standard model (SB 19) has been introduced for making diapositives of the same nominal format as the negative.

The transformation ratio of the standard printer is $\pm 2\%$. The ratio of the universal model is $1:1.5$ and $1.5:1$, over a range of $9\text{ in.} \times 9\text{ in.}$ ($23\text{ cm} \times 23\text{ cm}$) to $6\text{ in.} \times 6\text{ in.}$ ($15\text{ cm} \times 15\text{ cm}$).

Both models employ a distortion-free 7-inch f/10 projection lens. Other features common to both printers are adjustment to compensate variations of camera principal distance, centring adjustment after clamping the negative, and a choice of cold-cathode or multiple filament lamp illumination. They can also be supplied with electronically controlled cathode-ray tube illumination, to provide automatic shading or 'dodging'.

The standard $9\text{ in.} \times 9\text{ in.}$ and $7\text{ in.} \times 7\text{ in.}$ ($18\text{ cm} \times 18\text{ cm}$) plateholders available for both printers, embody a plane-parallel compensating plate, but camera lens distortion may be eliminated by alternative plateholders incorporating an appropriate aspheric correction plate.

The average exposure time is 5 to 7 seconds with cold-cathode illumination, and 8 to 12 seconds with multiple filament lamps. An automatic timer with a range of 3 to 60 seconds can be pre-set to control the length of exposure.

The spool carriers are provided with adaptors to take all film spools complying with B.S. 2940, as well as those of continental manufacture. Spooled film up to $9\frac{1}{2}$ in. (24 cm) in width, and 500 ft (150 m) in length can be accommodated.

Micro-step precision potentiometer. Cambridge Instrument Co. Ltd., 13 Grosvenor Place, London, S.W.1.

This instrument has a discrimination of one in 20 million over a single range of 2 volts. Its accuracy is claimed to be better than $\pm 0.001\%$ on the 2 volt dial, and direct readings are in steps of $0.1\text{ }\mu\text{V}$. The instrument is constructed in the form of a double potentiometer, but it requires only one galvanometer. Temperature compensation is provided for the standard cell from 10°C to 35°C .

Notes and comments

New Edition of *Notes for Authors*

With the amalgamation of The Institute of Physics and The Physical Society it is desirable to co-ordinate the production of the journals, hitherto published by the two bodies separately.

As is to be expected, the styles employed in the two sets of publications have differed in certain details, and we hope to remove most of these differences with the new volumes just starting. The main alteration which affects the *Journal of Scientific Instruments* and the *British Journal of Applied Physics* is in the form in which references are given. In future this will conform to the Harvard system.

To assist intending authors a revised *Notes for Authors* has been published and is available free of charge from 47 Belgrave Square, London, S.W.1, or 1 Lowther Gardens, Prince Consort Road, London, S.W.7. It contains hints on the preparation of scripts and diagrams, the layout of mathematics and the correction of proofs. Various appendices give lists of preferred spellings, symbols, abbreviations, form of references to be used and a bibliography of reference books and works on technical writing. Intending authors are invited to apply for a copy.

The Institute of Physics and The Physical Society Awards and Appointments

The Council of The Institute of Physics and The Physical Society which recently amalgamated has made the following Awards:

The Duddell Medal to Dr. J. B. Adams, the Director-General of C.E.R.N. (the European Organization for Nuclear Research), for his leadership of that team.

The Charles Vernon Boys Prize to Professor A. W. Merrison of the University of Liverpool for his distinguished research in experimental physics.

The Charles Chree Medal and Prize to Dr. S. E. Forbush of The Carnegie Institution of Washington for his distinguished work on the cosmic radiation.

The Council has also made the following appointments:

Guthrie Lecturer: Dr. D. Shoenberg of the Royal Society Mond Laboratory, Cambridge, has been appointed Guthrie lecturer for 1961.

Thomas Young Orator: Dr. H. H. Hopkins of the Imperial College of Science and Technology has been appointed to deliver the Thomas Young Oration in 1961.

Editorial and publications sales offices

Readers are requested to note that all correspondence of an editorial nature should now be sent to the following address:

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British Journal of Applied Physics Contents of the January issue

EDITORIAL

CONFERENCE REPORT

Summarized proceedings of a conference on stress analysis—University of North Staffordshire, April 1960. By C. D. Pomeroy.

PAPERS

- Improvements of photoelastic technique for strain measurement on flat surfaces. By G. Clyne, H. Fessler and R. W. Wilson.
Growth of crystals in glass. By J. G. Morley.
Method for calculating boundary value problems in heat conduction for cylindrical cavity and the half space, by means of convolution integrals. D. W. Jordan.
Interferometric measurement of small angular displacements Part 2. The double-slit Jamin interferometer. By P. Hariharan and D. Sen.
Interpretation of ultrasonic echo amplitude. By J. C. V. Rumsey.

CORRESPONDENCE

Measurement of the tensile strength of brittle materials. By A. Orr and R. Berenbaum and I. Brodie.

NOTES AND NEWS

Notes and comments

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Some developments and applications of the optical lever

R. V. JONES, M.A., D.Phil., Department of Natural Philosophy, University of Aberdeen

received 10th November 1960, based on the Duddell Medal lecture delivered at University of Reading on 1 September 1960

Abstract

The history of the optical lever is briefly reviewed from its invention by Poggendorf in 1826 to the recognition by Ising (1926) of Brownian fluctuations of a galvanometer in the records obtained by Moll and Burger in 1925 with their thermoelectric relay.

The design of optical levers and amplifiers by the author and his collaborators is outlined; these give sensitivities of order 10^{-10} radian for a mirror $2.0 \text{ mm} \times 2.0 \text{ mm}$, an observation bandwidth of 10 c/s. The effects of deflection currents and photon fluctuations are indicated. Applications of optical levers to a range of measurements, including Brownian fluctuations, radiation pressure, air expansion and infra-red detection are described. Optical and photoelectric systems similar to those developed for the optical lever can be used for alignment measurement; applications include refractometry for active index changes of order 10^{-9} , and a test of the constancy of the velocity of light in a transverse magnetic field.

THE optical lever was first described by Poggendorf in 1826. He said that he would not have thought the device worthy of publication were it not for a particular application, which obviated the need for special non-magnetic laboratories. An observer could fix a mirror to a compass needle, and mount the assembly in a small weather-proof enclosure in his garden; he could thus follow its day-to-day variations in direction by observing the image of a distant object reflected in the mirror, by means of a theodolite conveniently sited in his house. Poggendorf's mirror was $2.5 \times 3 \text{ cm}$ in size, and he estimated the limiting accuracy (by the theodolite) as 5 second of arc, or approximately 40 000.

The device was adopted by Gauss and, following him, Bessel (1846); they replaced the distant reference mark by a scale, and the theodolite by a telescope. This form of the instrument is still employed. The other well-known form is due to Kelvin (Thomson 1867), who at first used an illuminating slit, and focused an image of this slit, after reflection in the mirror, on to a scale; with this system, Kelvin initiated continuous photographic recording. At the suggestion of Bessel, Kelvin replaced the slit by a wire silhouetted by a circular patch of light, for visual observation, thus producing the standard lamp-and-scale system.

The optical lever was a powerful aid to the torsion balance, which had been invented, according to Cavendish (1798), in 1750 by Michell, who (without the torsion balance) discovered the law of force between magnetic poles. The balance was independently invented by Coulomb (1785), who used it in his investigations of electrostatic and magnetic forces; Michell does not appear ever to have used the torsion

balance himself, but his apparatus was taken over by Cavendish, and used in his classic experiment on the constant of gravitation. Cavendish, incidentally, had no optical lever, and so had to use a very long beam (6 ft) in his torsion balance, giving a time of swing of about 15 minutes.

The combination of the optical lever with the torsion balance was vital to some of the most celebrated experiments in classical physics. It will be sufficient to recall the determination of the gravitational constant by Boys (1895), the experimental confirmation of radiation pressure by Lebedew (1901), and the researches of Rubens and Kurlbaum (1900) and others into the radiation from a black body that led to Planck's formulation of the quantum theory. It would moreover be appropriate here to mention Duddell's (1909) application to his oscillograph.

In 1920, Wilson and Epps suggested that small changes in the direction of a beam of light reflected from an optical lever mirror might be more easily detected by instrumental means than by the human eye. They proposed to place two thermopiles so that one half of the reflected beam fell on each thermopile; the two piles were connected back-to-back to a galvanometer, and thus in the equilibrium position there was no current through the galvanometer. If the direction of the reflected beam changed, more light then fell on one pile than on the other, and a current flowed through the galvanometer which might thereby be deflected through a much greater angle than that through which the original mirror had turned.

The idea was developed by Moll and Burger (1925) in their 'thermoelectric relay'; their use of this relay with one of their own galvanometers showed that this had an inherent small unsteadiness. Moll and Burger thought that the cause might be microseismic disturbance, but, in one of the most vital papers in the history of physical observation, Ising (1926) identified the unsteadiness as due to the Brownian movement of the galvanometer coil as predicted for a suspended system by Smoluchowski (1912) and de Haas-Lorentz (1913). Ising's paper appears to be the first experimental recognition of the fundamental limits set to the precision of physical observation by the discrete structure of the Universe; it fittingly marked the centenary of Poggendorf's invention.

After 1930, photoelectric cells replaced thermojunctions as the detecting elements in optical lever systems; the design of a typical system is shown in Fig. 1 (Jones and Richards 1959). The source S is a miner's cap lamp bulb rated at 3.2 w at 4 v; an image of S is focused by the lens L_1 on to the optical lever mirror M, which is attached to the system whose rotation is to be measured. The light reflected from M diverges until it reaches L_2 ; this lens is exactly similar to L_1 , and it focuses an image of M, and therefore of S, on the surface of a double photocell X_1X_2 (a cadmium selenide photo-conductive cell, with two sensitive areas each

5 mm $\times$ 1 mm). Interposed between L_1 and M and L_2 is a subsidiary system consisting of a lens L_3 situated near the mirror M, and two grids G_1 and G_2 . G_1 is illuminated by converging light from the lens L_1 , and is so situated that the rays diverging from any point on G_1 are made parallel by L_3 ; after reflection from M, these rays return through L_3 to

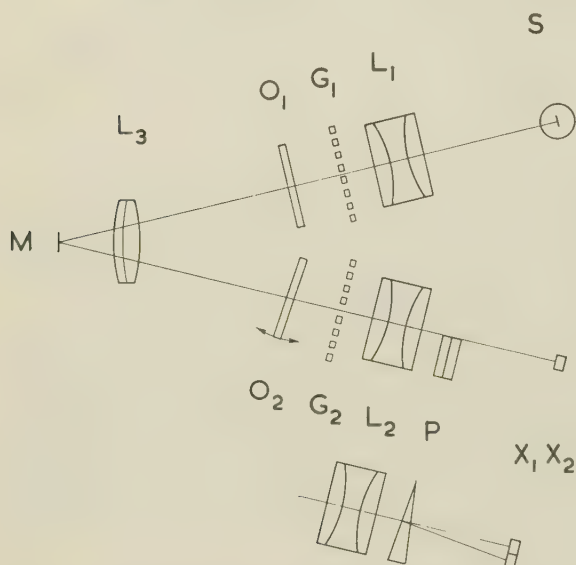


Fig. 1. Schematic plan of optical lever. Components L_2 , P, $X_1 X_2$ are shown also in elevation.

be focused in the plane of G_2 . Thus an illuminated image of G_1 appears in the plane G_2 ; this is the standard autocollimating position, and results in a distortion-free image at unit magnification. If G_1 and G_2 are replicas, G_2 will stop or pass the light from G_1 , depending on their relative positions transverse to the light path. G_2 is split into two halves so that when the right half of G_2 passes the light from G_1 , the left half of G_2 stops the light from G_1 ; this arrangement was first used by Pfund (1929). A narrow-angled prism P is placed behind one half of L_2 , so as to divert the light from this half to fall as a focused image on the lower half X_2 of the photocell. Light passing through the other half of G_2 and L_2 is undiverted, and forms a focused image of S on the upper half X_1 of the photocell. There is thus an image of S falling on each half of the photocell; as M rotates the intensities of the images change, due to the varying degrees of overlap between the image of G_1 and the two halves of G_2 .

In order to adjust the transverse position of the image of G_1 , an optical micrometer plate O_2 is placed in front of G_2 ; a similar plate O_1 is placed in the incident beam to maintain the symmetry of the system.

The grid spacings selected depend on the application; finer grids give greater effective sensitivity at the expense of maximum measurable rotation. A limit to the fineness of the grid that can be used is set by the aberrations of the system, and by the diffraction at M; generally grids of between 5 and 70 lines per cm are suitable. The grids may be made in several ways; a convenient method is to make a wire grid, and then to take replicas by evaporating aluminium through it on to glass.

The construction is outlined in Fig. 2. The base is about 20 cm long; it has to be sufficiently substantial to avoid any danger of components shifting unintentionally, and care must also be taken to avoid temperature changes which would

cause a similar effect. The desired mechanical movement of the optical micrometer plate O_2 is achieved by mounting on a cross-strip hinge. Both in this application and in many others involving fine mechanical adjustment spring movements are much easier to make than those based on kinematic design.

The electrical arrangements are comparatively simple owing to the high sensitivity of the cadmium selenide photocells. Very convenient transistor amplifiers have been developed by my colleague, Dr. J. C. S. Richards (Jones and Richards 1959).

The instrument is made as small as possible, and the light path is covered by a suitable container. This point is particularly important, since one of the worst causes of disturbance in optical levers is the irregularity of refractive index of air in the light path produced by convection currents (Jones 1951a). These currents have been a frequent trouble in the measurements of classical physics; Cavendish (1798) was perhaps the first to appreciate their importance, and it is suggested that they could be reduced by enclosing the apparatus in as small a container as possible. Boys (1895) investigated the effect of convection currents in his gravitation experiment, and he concluded from a dimensional argument that the effects increased with the fifth power of the linear dimension of the container. A few years ago, in his Guthrie Lectures (1954) to The Physical Society, Sir Geoffrey Taylor discussed

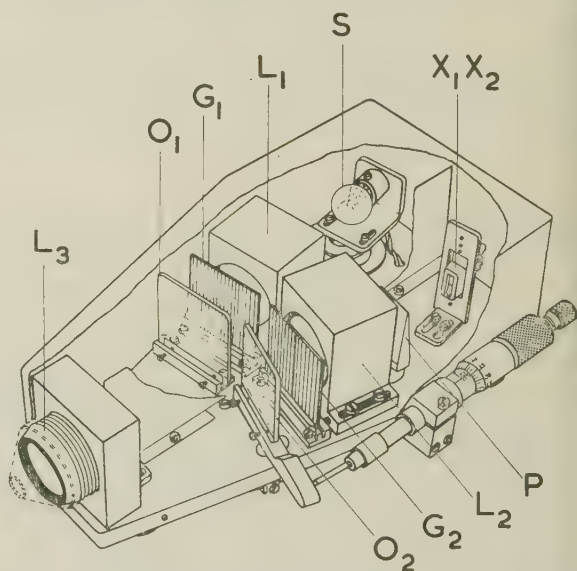


Fig. 2. Construction of optical lever. Overall length of base plate = 20 cm.

conventional equilibrium, and showed that convection currents in a tube will cease, even when there is denser fluid at the top of the tube and lighter fluid at the bottom, if the vertical density gradient becomes less than a critical value which is inversely proportional to the fourth power of the tube diameter. Sir Geoffrey pointed out that while the system might be expected to be unstable when the denser fluid is at the top, this is not true unless the difference in density exceeds a critical value. The instability would tend to result in the heavier fluid tending to flow down one side of the tube, while the lighter fluid would flow upwards at the other side. Diffusion would take place across the boundary between the downward current and the rising counter-current, which would tend to result in an equalization of density, and thus

sation of the current. If the original difference in height is small enough, the current will cease before the fluid level at the top has reached the bottom.

These considerations are substantially borne out in practice. The effects of convection currents, which are quite important when an optical lever is placed in a large container, can often be suppressed sufficiently to be unobservable when the light path is shrouded by a closely fitting container. Any variations of the refractive index of the air in the light path tend to divert light from one photocell, so that it falls elsewhere (even, perhaps, on the other photocell) and this gives rise to apparent fluctuations in the output of the instrument when the optical lever mirror is fixed. In effect, the optical design is that of a multi-slit schlieren system, and it is correspondingly sensitive to convection currents if they occur. Figure 3 shows the disturbance caused by leaving a gap of 2 mm between the narrow end of the conical shield (shown dotted in Fig. 2) and the optical lever mirror.

When suitable precautions are taken, it is possible to use optical levers at high sensitivity. With an optical lever mirror measuring $2.0 \text{ mm} \times 2.0 \text{ mm}$, and a recording speed of 10 c/s, the root mean square of the zero variation in the amplifier output is found in some recent instruments to correspond to rather less than 10^{-10} radian movement of the optical lever mirror.

It is worth noting that such a sensitivity is very much higher than the resolving power of the optical lever mirror, as conventionally defined. The resolving power is not an appropriate criterion to apply, however, because we are not concerned with the separation of two overlapping diffraction patterns, but with the precision with which the centre of a single diffraction pattern (that from the mirror) can be determined. In fact, from the experimental figures it appears that we can achieve a precision of between 10^6 and 10^7 times the resolving power, with an observation time of 1 second. If we look at the problem of establishing the centre of a diffraction pattern by counting the number of photons falling in each half of the pattern, this achieved accuracy implies that there must be at least of the order of 10^{13} photons falling in each half of the diffraction pattern during the time of observation (about 1 second). Measurement of the actual amount of light falling on the photocells indicates that the flux of photons in the light beam is not very much greater than 10^{13} per second. It therefore appears that we must be approaching the limit of precision of optical levers set by photon fluctuations in the light beam.

Our optical levers at Aberdeen have been used in several applications over the last ten years. The first investigation (Jones and McCombie 1952) concerned a precise determination of the thermal fluctuation limit of galvanometers. While

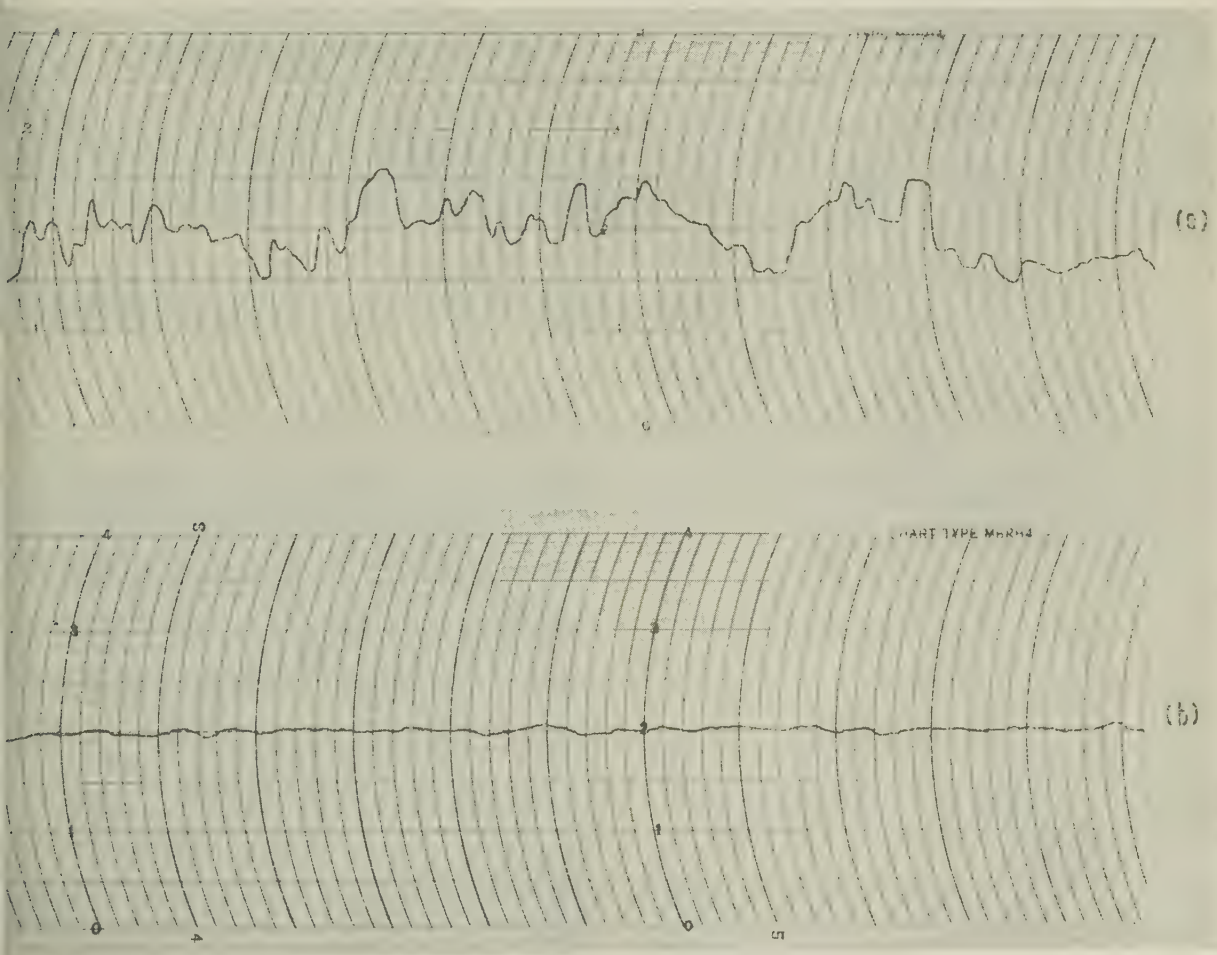


Fig. 3. Record (a) showing effects of convection currents in disturbing the balance of an optical lever when there was a 2 mm gap left between the conical shield (shown dotted in Fig. 2) and the optical lever mirror M. Sensitivity about 3×10^{-9} radian/vertical division. Record (b) showing balance obtainable with same instrument as that used in record (a), with gap closed. Sensitivity about 1.5×10^{-10} radian per vertical division. On both records 1 horizontal division = 2 seconds.

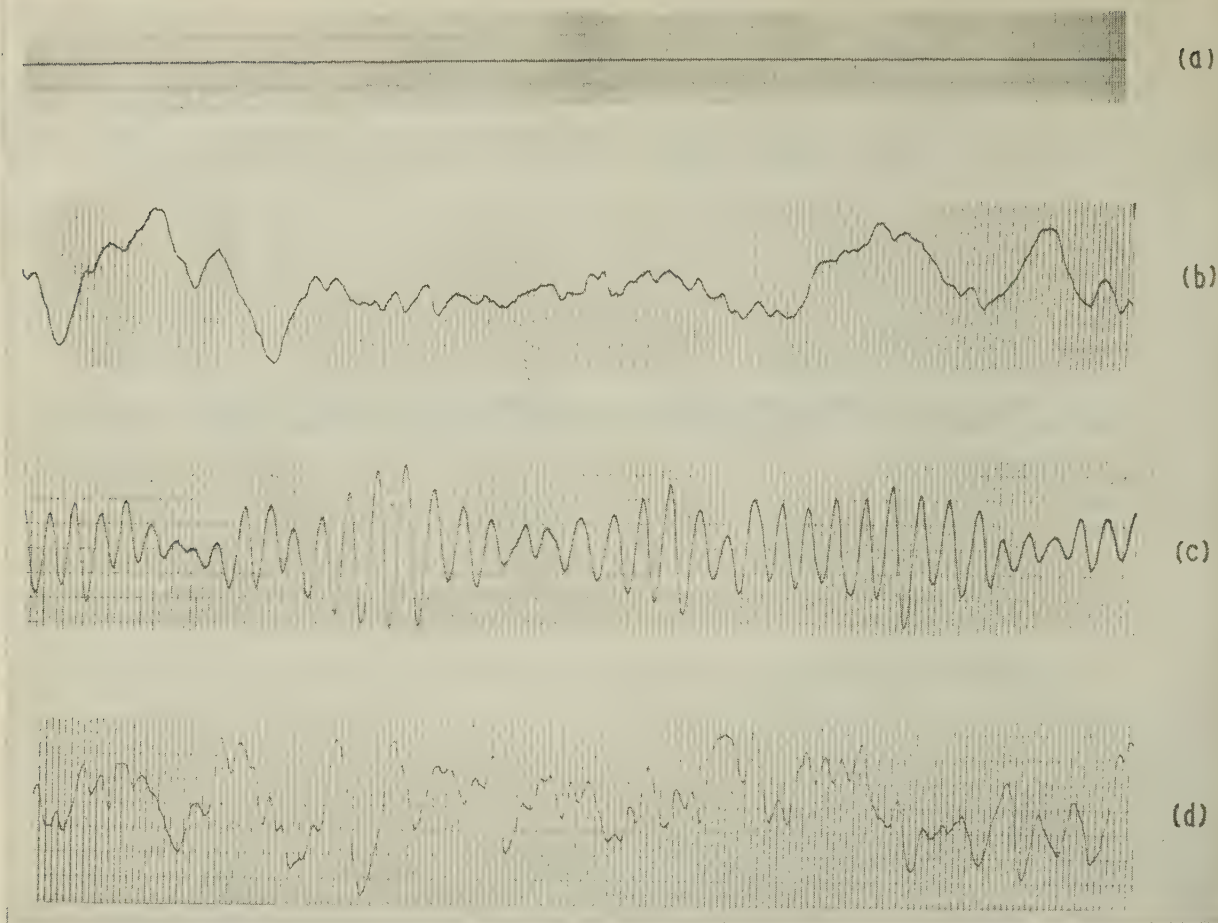


Fig. 4. Records of fluctuation of a galvanometer (free period 2.2 second) with different amounts of electromagnetic damping. The mirror is fixed in (a). The galvanometer is short-circuited in (b), open-circuited in (c) and critically damped in (d). Sensitivity is about 1.5×10^{-8} radian per division. Duration of record = 90 seconds.

previous investigations had shown approximately that galvanometer fluctuations could be explained by assuming that Brownian movement or Johnson noise gave the galvanometer coil a mean potential energy of rotation of $\frac{1}{2}kT$ (where k is Boltzmann's constant and T is the absolute temperature), the experimental limit had not been sufficiently precisely established to show that the potential energy was exactly equal to $\frac{1}{2}kT$ and not, for example, to $\sqrt{2}$ times this value as had been argued by some workers. Some of our records are shown in Fig. 4, which indicates that the root mean square displacement of the coil is almost the same for all three conditions of damping (much under-damped, critically damped, and heavily over-damped); and measurements of records such as these show that the potential energy in the system is exactly $\frac{1}{2}kT$ within the experimental error of 1%. The optical lever sensitivity had to be fairly high in this application, full scale deflection on the record corresponding to about 1.5×10^{-6} radian.

A second investigation concerned the pressure of radiation in a refracting medium. The experiments of Lebedew (1901), who confirmed the existence and magnitude of the pressure of electromagnetic radiation predicted by Clerk Maxwell, are among the most interesting in classical physics, and any experimenter might well wish for an opportunity of observing this pressure for himself. However, Lebedew per-

formed his experiments so thoroughly that there could be little point in repeating them, other than some personal satisfaction; but it occurred to me one day after demonstrating a simple 'corpuscular' model of refraction to my students that Newton would have said that a light corpuscle would gain velocity and hence momentum on entering a denser medium. Maxwell would also have predicted that the pressure due to radiation would increase under these circumstances, since the lower velocity of electromagnetic waves in the denser medium would necessarily increase the energy density. Moreover, on the modern picture, the momentum of a photon is h/λ , and therefore the momentum would increase since the wavelength decreases in the denser medium. All three viewpoints therefore lead to the same prediction that the momentum should increase in the ratio of the refractive index, but the effect had not, as far as I know, been observed. This gave me the occasion to observe radiation pressure for myself, and I therefore constructed an apparatus as indicated in Fig. 5 (Jones 1951b). The main difficulty in this experiment was that the momentum in the beam of light had to be measured both in air and in a fluid with a refractive index sufficiently different from unity to give a substantial increase of momentum. Radiation pressure is not easy to observe, except in vacuum where radiation meter and convection effects can be eliminated, but on this

sion it had to be observed not only in air at atmospheric pressure, but also in a liquid. However, from previous experience with convection currents I hoped that by making apparatus sufficiently small, convection difficulties could be reduced enough to make the experiment feasible. This

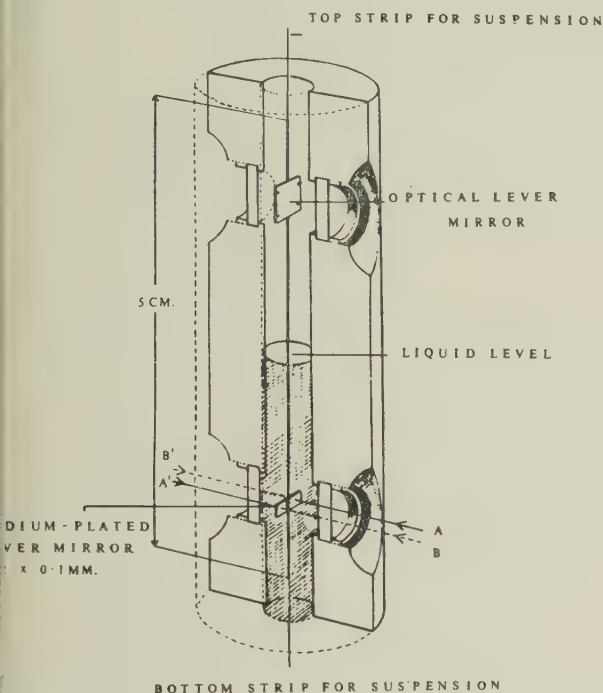


Fig. 5. Suspended system for radiation pressure measurements in a liquid.

ed out to be true, at least in air, and we (Jones and Hards 1954) obtained records such as that in Fig. 6, which shows the deflection of the system due to reversing the radiation pressure torque on the small mirror, at AA', by switching light beams from AA' to BB'. This small mirror was separate from the optical lever mirror visible at the top of the suspension.

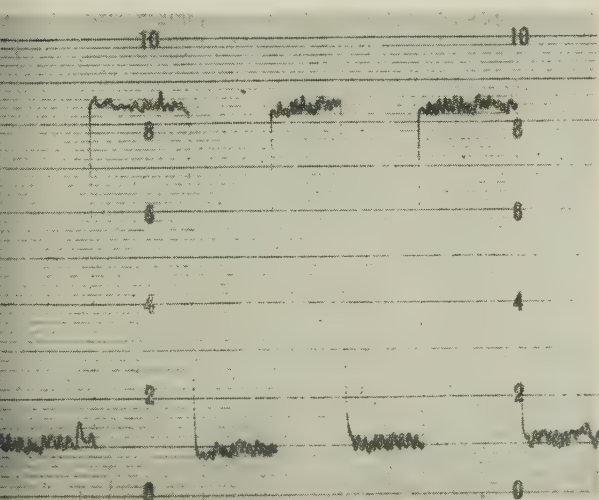


Fig. 6. Deflections due to radiation pressure acting on the suspended system of Fig. 5, in air. Full scale deflection $\sim 5 \times 10^{-5}$ radian. Duration of record = 100 seconds.

The phenomenon was more complicated when the radiation pressure mirror was surrounded by liquid, but it proved possible to distinguish between the genuine effect due to radiation pressure and the various other effects due to the heating of the vane and the surrounding liquid, by the fact that the radiation pressure was developed almost instantaneously, while the other effects required a few seconds to build up to full magnitude. It thus became possible to reverse the torque developed by the radiation pressure at a fairly rapid rate, by switching the incident light beams from position AA' to BB' (Fig. 5), and to look for the corresponding oscillation developed by reaction on the suspended system; the other effects were thus much reduced, since they had little time in which to develop. Measurements were not completely simple, since we then had the viscosity and other properties of the liquid to allow for, but these difficulties were overcome by adding a very small magnet to the suspension and arranging to deflect it by a magnetic field with the same frequency as that at which the light beams were switched. A comparison of the forces required to produce oscillations equal to those produced by the radiation pressure in air and in the liquid thus gave the proportionate increase in radiation pressure which occurred when the mirror was surrounded by liquid. The experiment was performed with sufficient accuracy to show that the increase was in the ratio of the refractive index of the liquid relative to air and there was just enough precision to indicate that the ratio was that of the phase velocity rather than the group velocity. In this application the sensitivity of the optical lever was such that full scale on the record corresponded to about 5×10^{-5} radian.

Another application of the optical lever has been to observe the increase in dimensions of a lithium fluoride crystal on exposure to x-rays. For this purpose a mirror was laid across two pieces of crystal about 1 cm long, one of the pieces being exposed to the x-rays, and the other piece of crystal screened. Fig. 7 shows the effect of an x-ray bombard-

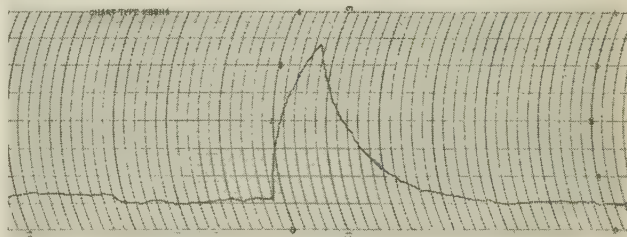


Fig. 7. Expansion and contraction of a 1 cm long lithium fluoride crystal with onset and cessation of x-ray bombardment. Full scale deflection $\sim 8 \times 10^{-9}$ cm. Duration of record = 115 seconds.

ment lasting a few seconds; full scale on this record is 10^{-8} cm, i.e. about an atomic diameter. The crystal contracts back to its original size after the x-rays have been switched off, and it is concluded that for such a small exposure the change in dimensions is probably due to thermal expansion, caused by energy absorbed from the x-rays, and not to F-centre formation.

A further application of the optical lever suggested itself when I was considering the possibility of making a detector of infra-red radiation that would approach the theoretical limit for a thermal detector more closely than had been achieved with a thermopile or bolometer (Jones 1959). I remembered that in 1934 Lord Cherwell, with whom I was

then working at Oxford, had pointed out to me that although thermal expansion was an unpromising effect owing to its small magnitude, the force available in the expansion was relatively large; if, therefore, one could find some way of using this force, a feasible infra-red detector might result. We had no idea at that stage how to magnify such a small change in length as would be involved but, in the light of what I had later found could be done with an optical lever, it was worth looking at the amount of magnification that would be needed.

The limit of useful sensitivity is set by the fact that when any receiver of thermal radiation is in thermal equilibrium with its surroundings, the equilibrium is established by the exchange of photons. There are necessarily statistical fluctuations in the number of photons being radiated and emitted both by the receiver and its surroundings, with the result that the total amount of energy in the receiver fluctuates from instant to instant. This means that the temperature will fluctuate; for an infra-red receiver of area about 1 mm^2 at 290°K , completely absorbing on the front surface and completely reflecting on the back surface, the temperature fluctuations, when observed with an amplifier of 1 c/s bandwidth, will in theory have a root mean square value of about 10^{-6}°C . Since a typical expansion coefficient is of the order 10^{-5} per degree, these temperature fluctuations will be manifest in a strip of nominal length 5 mm as fluctuations in length with a root mean square value of about $5 \times 10^{-12} \text{ cm}$. If, therefore, we have a way of detecting changes in length of this magnitude, we should be able to see the effects of temperature fluctuations in the receiver. Since we can detect rotations of less than 10^{-9} radian, it follows that we could detect a change of $5 \times 10^{-12} \text{ cm}$ in length if we had some way of converting the length change using a lever system with an arm of about 10^{-2} cm . A way of effecting this is to make use of the device shown in Fig. 8. The incident radiation falls on the expansion strip E, which acts as a pair of reins pulled tight around a taut suspension strip S of the type used in galvanometers. The radiation causes expansion of that part of E on which it falls, and this expansion allows the corresponding edge of S to move forward.

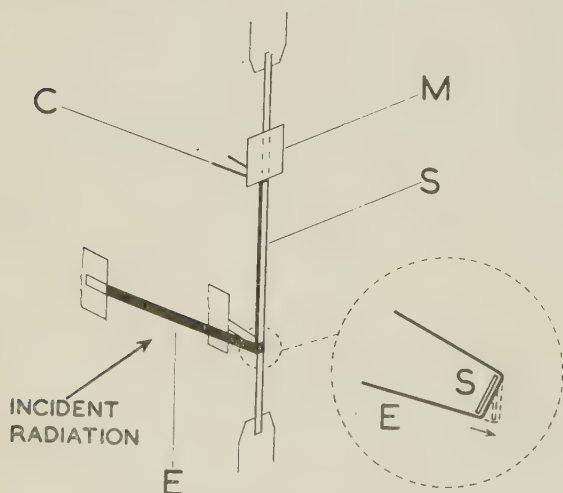


Fig. 8. Principle of expansion device. E, expansion strip 0.25 mm wide, 0.1μ thick; length on side receiving radiation 4 to 5 mm , length on other side 0.5 mm . S, suspension strip, 50μ wide, 5μ thick; total length 9 mm , length above mirror 2 mm , length below expansion strip 1.75 mm ; intermediate length of 3.5 mm between M and E copper plated to thickness of 50μ . M, mirror $1.5 \text{ mm} \times 1.5 \text{ mm} \times 0.06 \text{ mm}$. C, counterpoise for mirror, 5 mm of wire, 20μ diameter.

The part of S crossed by E thus rotates, and the rotation is transmitted to a mirror M, a few millimetres away from E so that the light falling on M from the associated optical lever does not heat E. The part of S lying between E and M is stiffened by copper plating, so that the full rotation of E is also experienced at M.

As regards the dimensions of the system as constructed (Fig. 9), the expansion strip is about 5 mm long $\times 0.2 \text{ mm}$

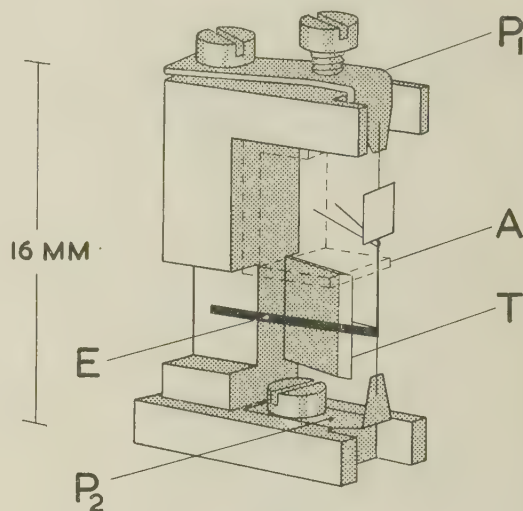


Fig. 9. Trial expansion device.

wide $\times 0.1$ micron thick; the material is constantan, to minimize heat loss by conduction. The suspension strip is about 50 micron in breadth and 9 mm long. The mirror is as light as possible, and is made of aluminized glass $1.5 \text{ mm} \times 1.5 \text{ mm}$ in area, and 60 micron thick. In order to reduce the effects of vibration, it is necessary to counterpoise the mirror to bring the centre of mass into the axis of rotation. This is achieved by a 'hairpin' of manganin wire about 4 mm long and 25 micron in diameter. The counterpoising has to be better than 1 microgram at 1 mm off axis.

This device is placed in a vacuum, and the mirror is observed by means of the optical lever system. Two of the records are shown in Fig. 10. In theory, the noise equivalent signal with a receiver of 1 mm^2 at 290°K and an observing bandwidth of 1 c/s should be about $5 \times 10^{-12} \text{ w}$. In the best of the records the observed noise for this area and bandwidth is about $1.0 \times 10^{-11} \text{ w}$. Thus, this device, using the apparently unpromising effect of thermal expansion as a transducer of infra-red into electrical signals, goes to within a factor of 2 of the theoretical limit. Of course, it would be a difficult detector to use, but it demonstrates the power of the optical lever as an observing device, and it may encourage the improvement of other forms of detector, such as thermopiles and bolometers.

The same techniques that have been applied for the measurement of direction in optical levers can easily be applied to direct measurements of alignment. In this application, the optical system can conveniently be made as shown in Fig. 11. The main difference between this system and that of the optical lever is, of course, that there is no reflection involved, and therefore the beam of light from the 'collimator' has to travel straight through to the 'telescope', and so one has to use two separate lenses L_2 and L_3 , instead of the single lens that was used to focus the grids in the optical lever. In the diagram, G_1 is at the principal focus of

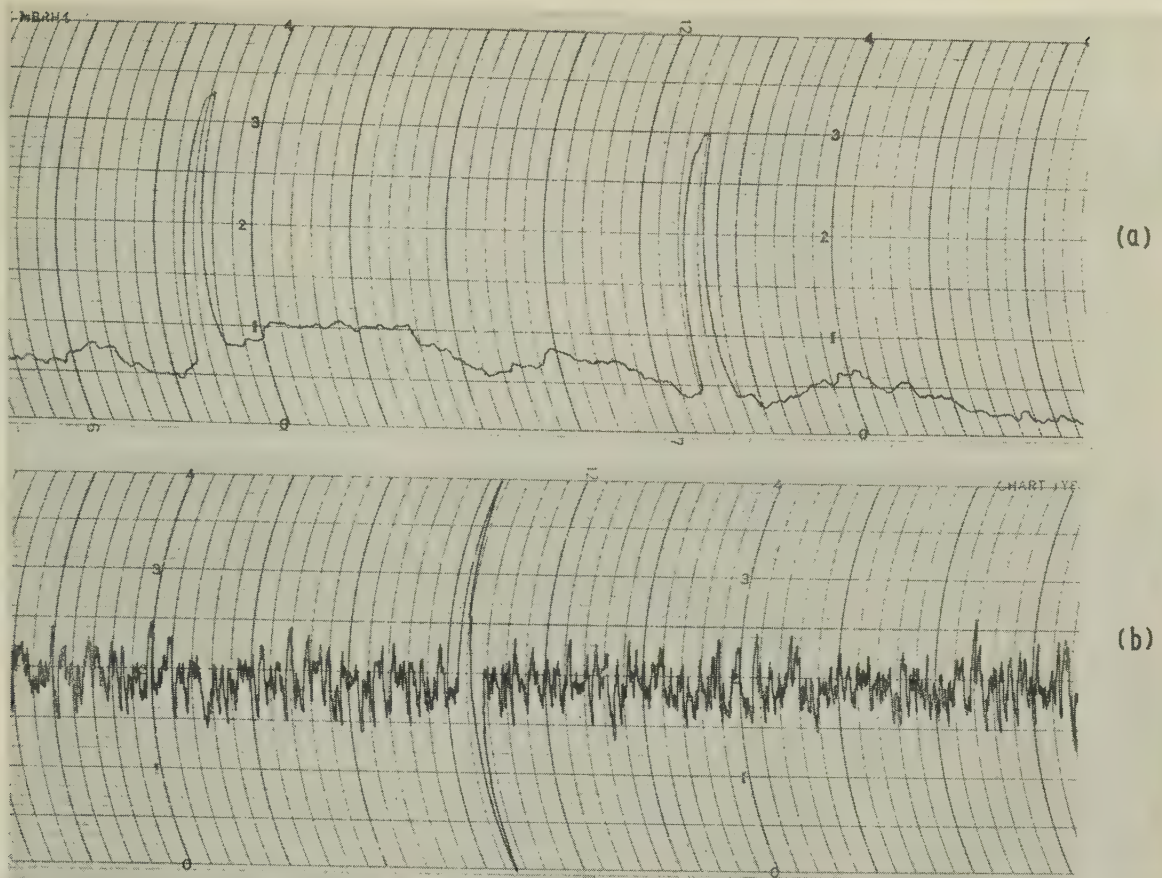


Fig. 10. Expansion device records. (a) Record showing zero drift, with superimposed deflections due to reception of radiation at rate of 1.7×10^{-9} w. One vertical division represents an expansion of 5×10^{-11} cm, or a temperature rise of about 5×10^{-6} c. On the scale of original record, an expansion of 1μ would give a deflection of 5 km; the amplifier was operating at about one-fortieth maximum gain. (b) Record with capacitances inserted to eliminate drift, and amplification increased. Positive and negative deflections due to switching on and off incident radiation of magnitude 4×10^{-10} w. One vertical division corresponds to velocity of perhaps 30μ per annum. On both records 1 horizontal division = 2 seconds.

L_2 , and G_2 is at the principal focus of L_3 , which is an exactly similar lens to L_2 . In the applications in which I have been interested, I have separated L_2 and L_3 by the sum of their focal lengths, mainly to give a good working space between them. An image of the source S is formed at I , exactly half way between L_2 and L_3 , and if the light is subject to some

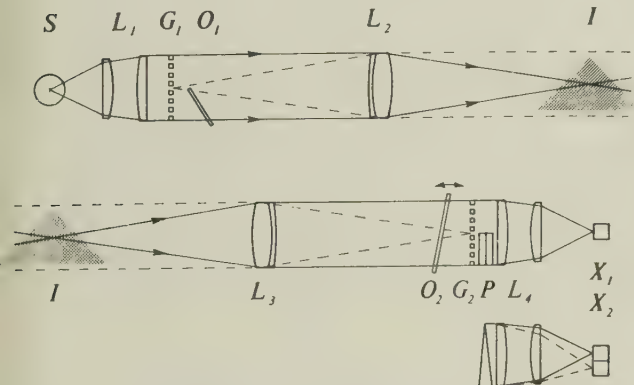


Fig. 11. Plan of optical system as used in alignment measurements. Components P , L_4 and X_1X_2 shown also in elevation.

change of direction in the neighbourhood of I , this is detected by the telescope system.

A refractometer on these principles can be made to detect small changes in the refractive index of the atmosphere when a trace of methane is present, as may occur in coal mines. For this purpose a 60° hollow prism is placed at I and any change in the refractive index of the gas inside causes a division of the rays passing through. Fig. 12 shows a record of the change in the refractive index of air, caused by changing the pressure inside the prism by a few millimetres of mercury.

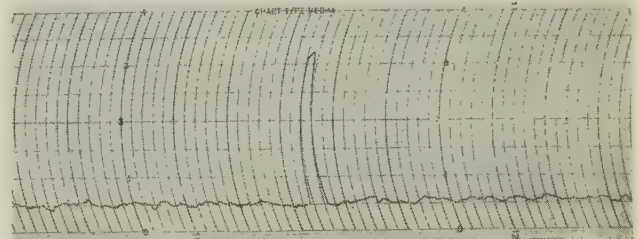


Fig. 12. Record showing response of a trial optical system as in Fig. 11, when used as a refractometer. The calibrating pulse is caused by a temporary change of refractive index of about 10^{-7} .

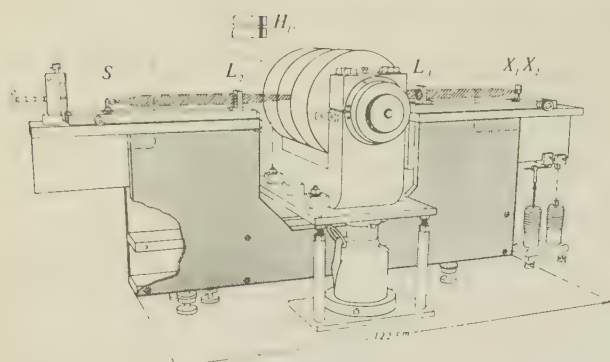


Fig. 13. Experimental arrangement for detecting a change in the velocity of light in a magnetic field.

The total change was of the order of one part in 10^7 , which corresponds to the change that would occur in the atmosphere if one part in 10^3 of methane were present.

From this application, it was clear that refractive index changes of the order of one part in 10^9 might be detected, and I therefore decided to apply the technique to looking for a change of the velocity of light in a transverse magnetic field. This effect has been sought at various times in the history of optics, the last occasion probably being the experiment by Banwell and Farr (1940). They achieved an accuracy of about one part in 10^9 , and found that there was a residual effect rather greater than their expected error, although they did not attach more significance to their result than that of setting an upper limit to any genuine effect. They had used an interferometric technique; I thought it worth while to attempt a similar experiment using the alignment technique.

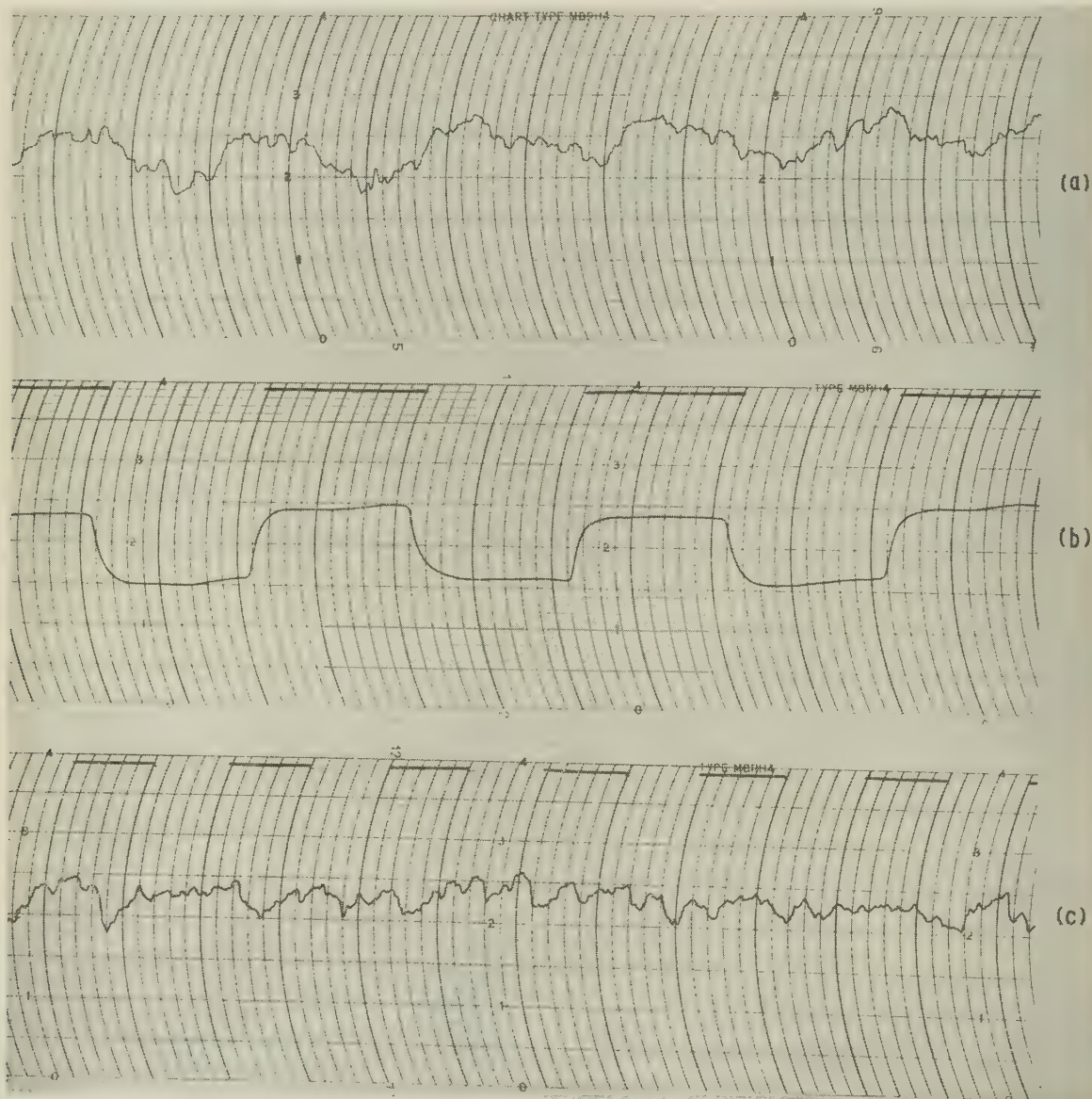


Fig. 14. Records taken with apparatus of Fig. 13. (a) Record taken at 70% full sensitivity, showing effect of rhythmic fluctuations of atmospheric pressure in bending the main base, before compensation was provided. Estimated maximum pressure fluctuation about 150 dyn cm^{-2} . (b) Record at one four-hundredth of full sensitivity, with air present in the light path through the magnetic field. Interrupted line at edge of record indicates when field was present. There is some unsteadiness, due to convection currents. (c) Record at full sensitivity (1 vertical division = 2.0×10^{-11} radian) with evacuated light path, and magnetic field alternately switched on and off. In all records, 1 horizontal division = 2 seconds.

tly to show that this would give at least as high a sensitivity as that achieved by interferometry. Actually, the probability of a positive result was small, but the experiment one that is worth repeating whenever sufficient improvement in sensitivity becomes available.

One of the main problems was to prevent the magnetic field from having any appreciable effect on the rest of the apparatus, and this fact decided the design of the base. There had to be substantial enough to prevent any undesired movement of the individual optical components and the design shown in Fig. 13 was adopted. The telescope and collimator were sited at either side of a region in which a uniform-shaped magnetic field was developed by specially shaped pole-pieces, rather like those used by Rabi (1929) in his modification of the Stern-Gerlach experiment. The light path was evacuated, partly because the containers had to be rather too large to inhibit convection currents, and partly because the magnetic field might have some effect on oxygen molecules in the light path. It was necessary to compensate for the effects of changes in atmospheric pressure, since this pressure acted in such a way as to tend to push the telescope and collimator together and thus to give an appreciable bending of the base, despite its substantial construction. The compensating device is visible at the right-hand end of Fig. 13; the atmospheric pressure changes on the flexible sealed capsules are made to provide a counter to the force acting on the telescope and collimator. The details of construction, together with the results, are given in more detail elsewhere (Jones 1961), but some of the records are reproduced here. Fig. 14(a) shows a record taken at 70% of full sensitivity, before the fluctuations of atmospheric pressure were compensated. It was taken during a very quiet period of weather in September 1959, and shows a regular fluctuation, of maximum amplitude about 150 dyn cm^{-2} . This fluctuation is of the same order as that caused in Britain when a hydrogen bomb exploded over the Pacific Ocean, but in this instance the fluctuation appears to have been due to some unidentified natural cause. Fig. 14(b) shows a record taken at 1/400 of full sensitivity, with air present in the light path through the magnetic field. There are relatively large deflections when the field is switched on, and these appear to be due to a migration of oxygen molecules in the magnetic field, giving rise to a difference in refractive index between the pole pieces; the maximum field is about 9000 oersted. Fig. 14(c) shows a record taken at full sensitivity, with the light path evacuated, and the magnetic field being alternately switched on or off. There is clearly no large effect due to the magnetic field, and this conclusion is borne out by detailed analyses of records covering about 8000 seconds of observation time.

In summary, it may be concluded that a transverse field of 100 oersted has no effect on the rate of propagation of light, to a root mean square error of $2.3 \text{ parts in } 10^{13}$, or about one micron per second. The complete absence of any effect is attributable to the action of the stray magnetic field on the rest of the apparatus is a satisfactory feature of the results, and is also the angular sensitivity obtained. While the limited nature of the main result must be emphasized, the detection of changes in refractive index of one part in 10^{12} is feasible;

alignment methods thus give a precision not only comparable with that of interferometry, but also with that of masers and Mossbauer techniques.

In conclusion, we can see that there are natural limits to the sensitivity of optical levers, just as there are for galvanometers, thermal radiation detectors, radio receivers and other instruments. Although instruments are not the ultimate objective of physics, those of us who feel the challenge of developing them to their limits may justify ourselves in much the same way as does the pure mathematician or the mountaineer, on the grounds of answering a challenge for its own sake. We may, moreover, also point to the positive results of meeting this challenge. If C. T. R. Wilson, for example, had not tried to make a perfect electroscope the discovery of cosmic rays might have been long delayed; and radio astronomy had its origin, not in theoretical speculation, but in Jansky's efforts to make a perfect radio receiver.

It has long been an encouragement that by perpetuating the memory of Duddell, The Physical Society has recognized this field of endeavour. It thereby honours not only those of us fortunate enough to receive the Medal, but also the many—the teachers, colleagues, technicians and previous workers in the field—on whom we gratefully depend.

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Design of scales for industrial instruments

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MS. received 10th November 1960

Abstract

After discussion of the results of various experimenters on the errors that may arise when reading instrument scales and possible means of reducing them, attention is given to recommendations being prepared by the British Standards Institution. Particularly important is the relationship between size of scale and reading distance and the correlation with this of sizes and spacing of the graduation marks and numerals. An analysis of possible scale ranges and the subdivision of these to proceed in number steps of 1's, 2's or 5's, shows that the number is limited and not all can conform to the desired optimum conditions of design; compromise is therefore necessary particularly in the degree of accuracy to which the scale may be read. The scale designs considered are suitable for industrial instruments having accuracies to the order of 1 to 2%.

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Mass spectrometer for the isotopic analysis of lithium

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Abstract

A mass spectrometer has been designed for the routine analysis of lithium. Microgram samples of lithium nitrate are ionized in a thermal ionization source. A 60° sector magnet analyses the two ion beams which are collected simultaneously on two separate collectors. The source is pulsed and the two signals are a.c. amplified and then subtracted from one another. The difference is displayed on a cathode-ray tube and the ratio is given rapidly by reading attenuation dials after adjusting for a null deflection. A calibration technique corrects for unequal transmission through the spectrometer and for inequalities in the circuitry. The precision of a single measurement of isotope ratio is $\pm 0.7\%$.

Introduction

A mass spectrometer has been designed for the rapid and simple analysis of routine lithium samples. The resolving power required for the analysis of this element is much lower than that of the commercially available mass spectrometers and, as the efficiency of thermal ionization of lithium is high, a simple detection method is adequate. It is desirable to reduce the effect of time variations of beam intensity by using a simultaneous collection method and a full-reading ratio indicator.

Several instruments for the analysis of lithium have been designed by the Research and Development Branch of the United Kingdom Atomic Energy Authority. The Metropolitan-Vickers machines, M.S.1, M.S.2 (Bishop and Bentley 1956) and M.S.3 (Bishop, Briercliffe and Bentley 1956) have been converted for this purpose, and an interesting 'Y' shaped mass spectrometer (Bentley, Bishop and Davidson 1956; Bentley *et al.* 1959), has been specially built. The latter has two separate source arms, either of which may be used with the collector to form a 60° mass spectrometer.

For the instrument about to be described, a conventional 60° magnetic mass spectrometer design was chosen with a radius of 6 in. Two separate collectors are used, one for each of masses 6 and 7. The two beams are pulsed by switching the potential of one of the source focusing plates, the output pulses are amplified and subtracted and the difference signal is displayed on a cathode-ray tube. Accurate attenuators are adjusted until the difference signal is zero and the isotopic ratio is read directly as the ratio of the attenuator settings for the two beams.

Source

An important consideration in the design of a mass spectrometer for the analysis of lithium is the effect of mass fractionation. The lighter isotope tends to evaporate preferentially giving an observed 6/7 ratio which is high by a

factor $(7/6)^{1/2}$. The triple-filament technique described by Inghram and Chupka (1953) and Palmer *et al.* (1954) has been shown to reduce the magnitude of the error. The sample as lithium nitrate in solution is painted on to nickel side flags. The central tungsten filament is directly heated and the side flags are heated sufficiently by radiation to evaporate the sample as neutral molecules of lithium nitrate. Dissociation and ionization occur at the central filament,

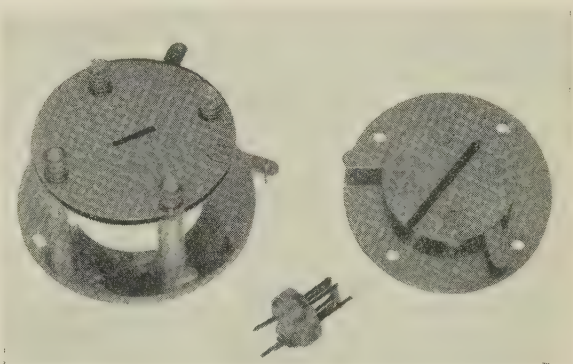


Fig. 1. Ion source.

and the possible error in ratio due to fractionation is therefore reduced from a factor of $(7/6)^{1/2}$ with a single filament technique to $(69/68)^{1/2}$.

The source is shown in Fig. 1 and schematically in Fig. 2. The slit widths and typical potentials for maximum beams are given in Table 1. The normal operating current through the filament (0.4 in. $\times$ 0.030 in. $\times$ 0.001 in.) is 3.5 A.

Table 1. Source slit widths and potentials

Source plate	Slit width (mm)	Potential (v)
Filament	—	2000
T	1.0	1990
D	2.0	1900
F ₁ , F ₂	3.0	500, 500
E	1.5	0

Ion path

The ion path was constructed from two flattened stainless-steel tubes welded together to form an angle of 120°. The centre section was machined to enable it to slide into the 0.5 in. wide pole gap. A beam of 5° total divergence can be accommodated and the slit is 0.5 cm high. Provision was made for adjustment of the position of the ion path relative to the magnet as indicated in Fig. 2, and this was used in the initial focusing procedure. No further adjustment was found

necessary. The connection to the baffle valve and the mercury diffusion pump is made *via* the two pumping ports shown in Fig. 2. The lowest pressure attained is usually 5×10^{-7} mm Hg, but a sample analysis is commenced when the pressure falls below 10^{-5} mm Hg.

The duration of the pulses is 10 ms and the recurrence frequency is 25 pulses/s. This frequency is the minimum which can be locked to mains frequency and at which flicker of the cathode-ray tube trace is not too objectionable.

Pulsing of the beam allows the use of an a.c. amplifier.

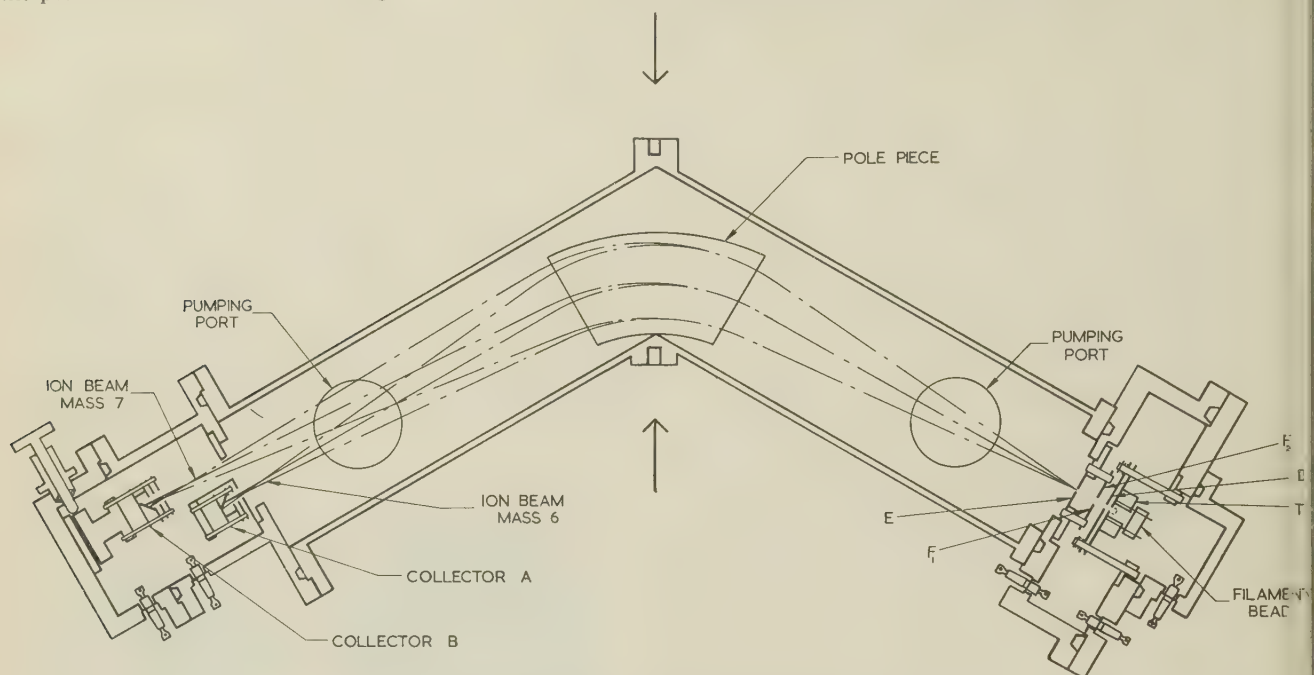


Fig. 2. Diagram of the mass spectrometer.

Magnet

As there already existed a magnet from a dismantled Dempster mass spectrometer, this was modified for use here by the addition of 2 in. thick pole pieces with the cross section shown in Fig. 2. Allowance of one-pole gap width was made for the fringing field. The field required to focus mass 6 in the symmetrical position is 1360 gauss.

Collector

Collector A (Fig. 2) is fixed in the position corresponding to the symmetrical beam. The adjustable earthed slit width is set at 5 mm, and the slit widths of the suppressor and the collector cup are 6 mm. Collector B is of similar construction, but it is mounted on a kinematic slide on the end cap of the collector (Fig. 3). The position of the defining slit is set at the calculated position for the mass 7 ion beam when the mass 6 ion beam is centred on collector A, and adjustment of the slide position externally through an O-ring seal, permits a small correction to be made for ion-beam displacement. The collector currents and the leads for the suppressors are brought out through glass-kovar seals.

Detection and ratio measurement

The source and collector electronic units are shown schematically in Fig. 4. In the absence of a trigger pulse from the pulse generator, the focus plate F_1 is held at approximately 50 v while F_2 is at its normal operating voltage of approximately 500 v. The beam is thus deflected and prevented from passing through the final slit. On receipt of a pulse, the potential of F_1 rises to approximately that of F_2 and the beam is transmitted normally through the spectrometer.

limited bandwidth. The troubles due to drift which are always associated with d.c. amplifiers are thus eliminated without the expense of using vibrating-reed electrometers.

Since the bandwidth is low (~ 1 kc/s) the noise level is correspondingly low and small signal amplitudes can be used. The theoretical magnitude of thermal-agitation noise present at the grid of the cathode follower with a 10 MΩ resistor is approximately $13 \mu\text{v r.m.s.}$ The Welwyn 'Parametric' range of high-stability resistors have a noise figure

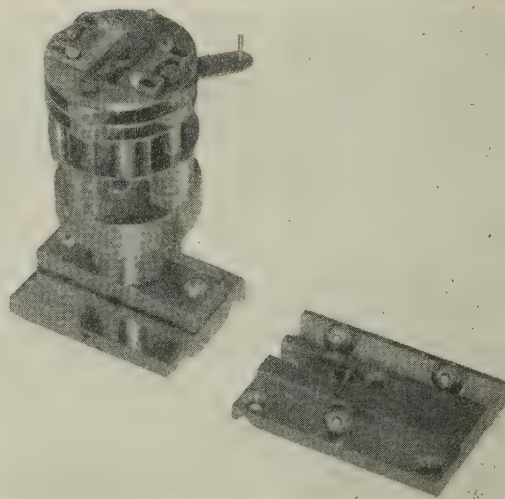


Fig. 3. Movable collector and kinematic slide.

ly slightly in excess of the theoretical minimum for potential differences of 1 or 2 v across the resistor.

The load resistor has been restricted to 10 M Ω in order to preserve a reasonable pulse shape. The rise time of the

collector is adjusted to make the pulse from the collector equal the standard pulse.

This technique corrects for several possible differences in the two circuits such as unequal transmission through the

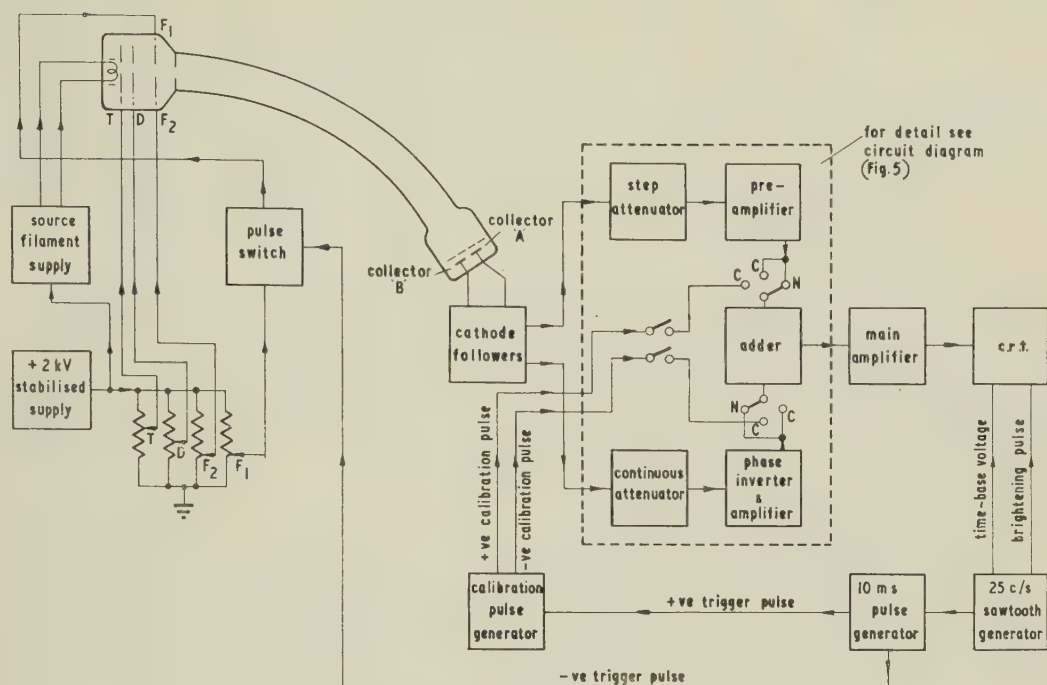


Fig. 4. Block diagram of the source and collector circuits.

leading edge of the pulse is approximately 0.4 ms, that is, 1% of the pulse duration. A considerable reduction in the effective collector capacitance could be obtained by surrounding the collector cup with an electrode at the same potential as the cathode of the cathode follower. Since the sensitivity is at present adequate, this modification has not been made.

The voltage pulses developed across the 10 M Ω load resistors are applied to separate cathode followers and thence to attenuators in the indicator unit (Fig. 5). One attenuator consists of switched 0.1% resistors and the other is a ten-turn helical potentiometer of 0.1% linearity. The output of one attenuator is amplified and inverted whilst that from the other attenuator is amplified without inversion. The two channels are now added and the output applied to the main amplifier. The major part of the amplification is carried out here ($\sim 5 \times 10^4$) and the output is fed to the Y-plates of the cathode-ray tube. By adjustment of the attenuators, the amplitude of the pulses can be made equal and a null is obtained on the oscilloscope. The ratio of the readings of the two attenuator dials gives the isotopic ratio. The circuits used in each channel are identical and the gains are adjusted in the calibration procedure.

Calibration

It is necessary to ensure that the two detector circuits are balanced. By switching the magnetic field, it is possible to switch the largest lithium beam on to each collector in turn. With the beam on collector A, the height of a standard pulse generated in the pulse unit is varied to balance the pulse from the collector. The beam is then switched to collector B and the preset potentiometer in the preamplifier circuit of this

ion path, unequal load resistors and unequal gain of the cathode followers.

Performance

To check the peak shapes and the magnitude of the scatter from one peak to another, the instrument was used as a conventional single-detection spectrometer. A vibrating-reed electrometer was connected to collector A and the isotopic beams were scanned by variation of the magnetic field. The result is shown in Fig. 6. The contribution due to mass 7 ions at the mass 6 position is less than 2×10^{-13} A, so that the ratio of the scattered beam to the parent peak height is less than 10^{-4} .

Using the ratio-detection system at maximum gain, the noise on the cathode-ray-tube trace is 2 mm broad, this corresponding to an ion current of 8×10^{-12} A or a peak-to-peak noise from the 10 M Ω resistor of 80 μ V. For accuracy of ratio measurement to 1%, the smallest beam must give at least 3 cm deflection on the cathode-ray tube at maximum gain. This corresponds to a minimum usable ion current for the smallest beam 1.2×10^{-10} A, and this is easily exceeded with 5 μ g of sample.

Repeated runs were made on standard samples, each time using a new filament bead and cleaning the source plates T and D. No preliminary degassing of the bead was performed and no errors resulting from this were detectable. In a typical run, the mean value of six results had a 95% confidence limit of $\pm 0.3\%$ (that is, $\pm 2\sigma/n^{1/2}$). The precision of a single measurement of isotope ratio was $\pm 0.7\%$ (that is, $\pm 2\sigma$) [σ is the standard deviation ($\sum \bar{x}')^{1/2}/n$, n is the number of results, $\bar{x}'$ is the deviation from the mean].

Results for three standard samples are shown in Table 2. It is seen that there is no significant difference between ratios

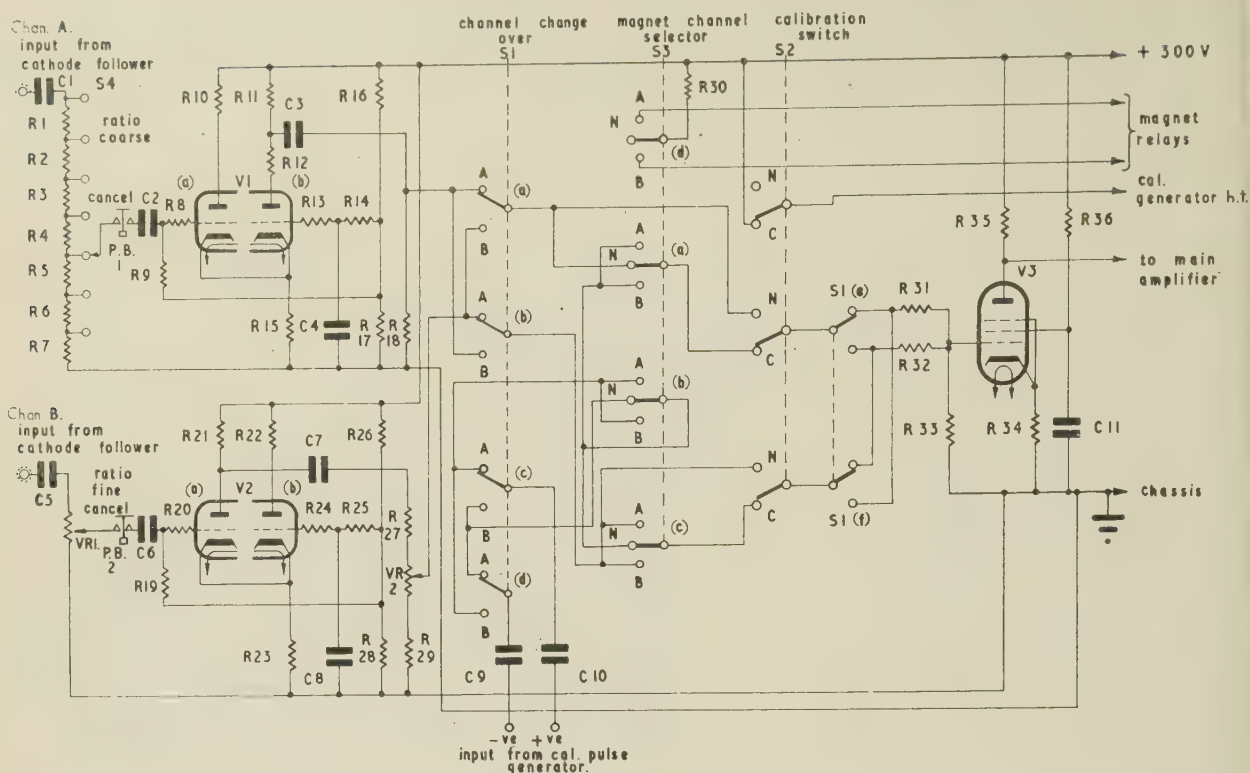


Fig. 5. Arithmetic circuit.

All resistors rated $\frac{1}{2}$ w and 10% tolerance unless otherwise stated.

$R_1 = 5 \text{ k}\Omega$, w.w., 0.1%
 $R_2 = 3 \text{ k}\Omega$, w.w., 0.1%
 $R_3 = 1 \text{ k}\Omega$, w.w., 0.1%
 $R_4 = 500 \Omega$, w.w., 0.1%
 $R_5 = 300 \Omega$, w.w., 0.1%
 $R_6 = 100 \Omega$, w.w., 0.1%
 $R_7 = 100 \Omega$, w.w., 0.1%
 $R_8 = 1 \text{ k}\Omega$
 $R_9 = 1 \text{ M}\Omega$
 $R_{10} = 50 \text{ k}\Omega$, 1%, h.s.
 $R_{11} = 39 \text{ k}\Omega$, 1%, h.s.
 $R_{12} = 11 \text{ k}\Omega$, 1%, h.s.
 $R_{13} = 1 \text{ k}\Omega$
 $R_{14} = 1 \text{ M}\Omega$
 $R_{15} = 4.7 \text{ k}\Omega$, 1%, h.s.
 $R_{16} = 300 \text{ k}\Omega$, $\frac{1}{2}$ w, 1%, h.s.

$R_{17} = 4.7 \text{ k}\Omega$, 1%, h.s.
 $R_{18} = 1 \text{ M}\Omega$
 $R_{19} = 1 \text{ M}\Omega$
 $R_{20} = 1 \text{ k}\Omega$
 $R_{21} = 50 \text{ k}\Omega$, 1%, h.s.
 $R_{22} = 50 \text{ k}\Omega$, 1%, h.s.
 $R_{23} = 4.7 \text{ k}\Omega$, 1%, h.s.
 $R_{24} = 1 \text{ k}\Omega$
 $R_{25} = 1 \text{ M}\Omega$
 $R_{26} = 300 \text{ k}\Omega$, $\frac{1}{2}$ w, h.s.
 $R_{27} = 120 \text{ k}\Omega$, 1%, h.s.
 $R_{28} = 4.7 \text{ k}\Omega$, 1%, h.s.
 $R_{29} = 270 \text{ k}\Omega$, 1%, h.s.
 $R_{30} = 27 \text{ k}\Omega$, 6 w, w.w.
 $R_{31} = 3.3 \text{ M}\Omega$, 1%, h.s.
 $R_{32} = 3.3 \text{ M}\Omega$, 1%, h.s.

All capacitors rated 350 v working and 20% tolerance unless otherwise stated.

$R_{33} = 1 \text{ M}\Omega$
 $R_{34} = 1 \text{ k}\Omega$
 $R_{35} = 56 \text{ k}\Omega$
 $R_{36} = 390 \text{ k}\Omega$, $\frac{1}{2}$ w

$VR_1 = 10 \text{ k}\Omega$, 10-turn helical potentiometer, 0.1% linearity
 $VR_2 = 500 \text{ k}\Omega$, 1 w carbon potentiometer linear

$C_1 = 25 \mu\text{F}$, 25 v electrolytic
 $C_2 = 1 \mu\text{F}$, 250 v working
 $C_3 = 1 \mu\text{F}$
 $C_4 = 0.1 \mu\text{F}$
 $C_5 = 25 \mu\text{F}$, 25 v electrolytic
 $C_6 = 1 \mu\text{F}$, 250 v working

$C_7 = 1 \mu\text{F}$
 $C_8 = 0.1 \mu\text{F}$
 $C_9 = 1 \mu\text{F}$
 $C_{10} = 1 \mu\text{F}$
 $C_{11} = 0.5 \mu\text{F}$

$V_1 = \text{ECC83 (CV492)}$
 $V_2 = \text{ECC83 (CV492)}$
 $V_3 = \text{EF86 (CV2901)}$

$PB_1, PB_2 = \text{Push button biased to make}$

$S_1 = 6\text{-pole, 2-way wafer switch}$
 $S_2 = 3\text{-pole, 2-way wafer switch}$
 $S_3 = 4\text{-pole, 3-way P.O. key}$
 $S_4 = 1\text{-pole, 7-way wafer switch}$

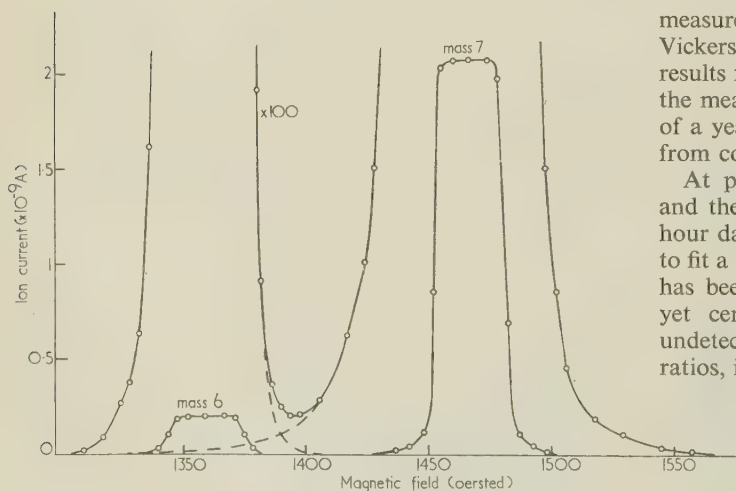


Fig. 6. Ion-beam shapes.

measured on this mass spectrometer and the Metropolitan Vickers Spectrometer, type M.S.5. The larger spread in the results for sample 3 on the M.S.5 may have occurred because the measurements were taken at various times over a period of a year, whereas the results for the first two samples were from consecutive measurements.

At present, no source vacuum lock has been provided and the sample analysis time, about five samples per eight hour day, is limited by the time to pump down. It is hoped to fit a source lock in the future. The new mass spectrometer has been in satisfactory operation for a year. As it is not yet certain whether all mass spectrometers produce an undetected systematic error in the measurement of lithium ratios, it is customary to quote ratios with accuracy to 2%.

Acknowledgments

We wish to record our thanks to Mr. H. Patterson and Mr. W. A. P. Young for contributions in the early stages of this work. The

Table 2. Comparison of measurements made on this mass spectrometer with ratios obtained on an M.S.5 mass spectrometer (95% confidence limits are given)

Sample	Ratio 7/6 (successive measurements with this spectrometer)	Mean ratio 7/6	Mean ratio 7/6 from M.S.5
1	12.24	$12.25 \pm 0.3\%$	$12.21 \pm 0.2\%$
	12.32		
	12.29		
	12.32		
	12.26		
	12.16		
	12.21		
2	12.20	$2.086 \pm 0.4\%$	$2.088 \pm 0.5\%$
	2.080		
	2.113		
	2.065		
	2.095		
	2.084		
	2.074		
3	2.082	$0.1131 \pm 0.3\%$	$0.1127 \pm 1.5\%$
	2.084		
	2.095		
	0.1127		
	0.1139		
	0.1130		
	0.1131		
	0.1132		
	0.1129		

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Transistorized vacuum trip unit

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Abstract

A vacuum trip unit has been designed, using a thermocouple gauge and a transistorized d.c. amplifier, to operate relays in the interlock and protection circuits of a high-vacuum pumping system. The unit is simple to construct and set up, yet has proved stable and reliable in operation.

Introduction

IN large or complex high-vacuum systems it is essential to have devices which will protect the installation from mishaps. For instance, it is undesirable to bring in oil-diffusion pumps when the backing pressure is in excess of a few hundred microns (μ). A vacuum trip unit connected to a thermocouple gauge in the backing line could prevent such an occurrence. Also it could switch off the heaters of diffusion pumps and close backing-line valves in the event of an excessive rise in pressure. This paper describes a transistorized unit which is simple and inexpensive, and which has proved very reliable in use on the Rutherford Laboratory proton linear accelerator.

Description

The unit consists of three main parts, namely the thermocouple gauge, the amplifier and the relay stage (Fig. 1). The gauge is connected into the vacuum system, and changes in

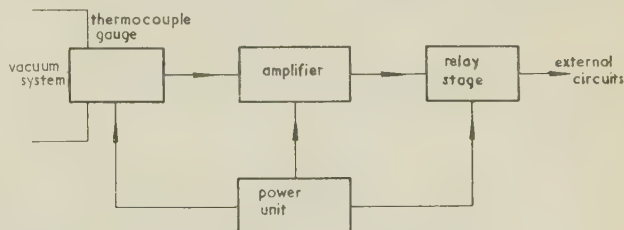


Fig. 1. Block diagram of trip unit.

its output resulting from pressure variations are amplified before being used to operate the relay stage.

Thermocouple gauge. The principle of this gauge is as follows. For constant heater power, the temperature of a heated wire is inversely proportional to the gas pressure in

which it is placed. If a thermocouple is in thermal contact with the wire, then the output can be calibrated in terms of the gas pressure. The gauges used on the proton linear accelerator are Metropolitan-Vickers gauges, type VH8, which require a heater current of 5 to 7 mA, and give an output of about 9 mV in high vacuum ($< 5 \mu$ say). These are about to be replaced by the more recent gauge, type VC8M of similar specification. The output from the gauge head is then fed into the amplifier.

Amplifier. The operating point of the unit should obviously be as stable as possible, one cause of drift in an amplifier being temperature variation. The trip unit was to be installed in an area subject to a fairly wide temperature change, and consequently it was necessary to choose a type of amplifier that would compensate for the temperature-induced drift (Chaplin and Owens 1958).

In a basic common-emitter amplifier (Fig. 2), a change in temperature produces a change in the leakage current i_{co}

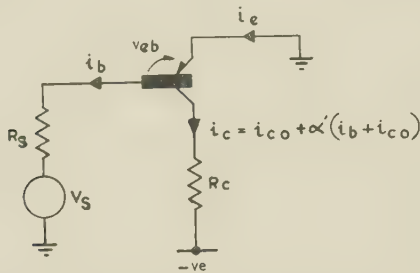


Fig. 2. Basic common-emitter amplifier.

and the base-to-emitter voltage v_{eb} , both causing the collector current and hence the collector voltage to drift. If a silicon transistor is used i_{co} is reduced to about $0.5 \mu A$ for the Mullard type OC201F, and therefore the change Δi_{co} becomes negligible over a range of, say, 20 deg C. The change in v_{eb} can be compensated for by using a similar transistor as shown in Fig. 3.

If the transistors are in a common thermal junction, Δv_{eb1} , Δv_{eb2} and Δi_{co1} , Δi_{co2} will be equalized respectively,

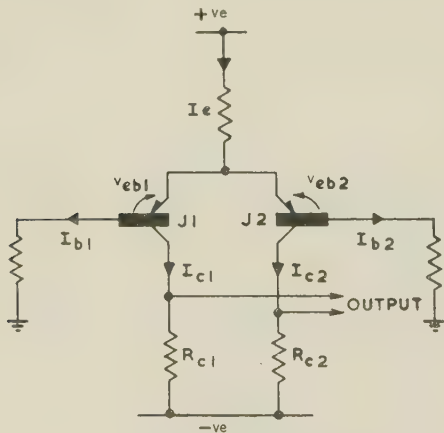


Fig. 3. Compensating for changes in v_{eb} .

provided the transistors are matched. Thus a change in I_{c1} will be matched by an equivalent change in I_{c2} , so that if the output is taken as a difference signal from the collectors, it will be zero for current changes due to temperature variations. However, a change in signal voltage applied to the base of J_1 will cause an unbalanced condition, and a voltage change

will be produced at the output. This output signal in vacuum trip unit is insufficient to operate the relay directly, so further amplification is necessary, and the output is therefore fed to the common-emitter amplifiers shown in Fig. 4. Negative feedback is taken from collectors of J_3 and J_4 via resistors R_5 and R_6 to stabilize the operation of the amplifier in the linear region.

To offset the fairly low gain (~ 30) of the OC201F, it was decided to use the comparatively high-gain (~ 100) OC44 transistors in the final stage. These are quoted as having an average leakage current of about $25 \mu A$, which is quite large

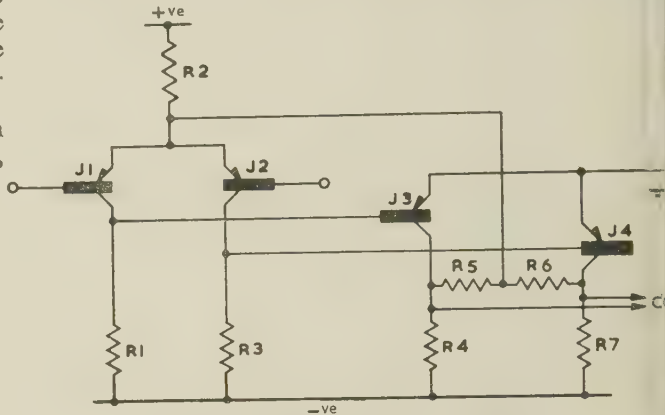


Fig. 4. Further stages of amplification.

in this circuit. However, in a multi-stage amplifier, given reasonable stage gain, drift at the output can be assumed to originate entirely in the input stage (Chaplin 1957-58). Thus in this last stage of amplification, temperature changes produce relatively unimportant variations in output current. These variations are minimized further by repeating the precautions taken in the input stage, that is, J_3 and J_4 are

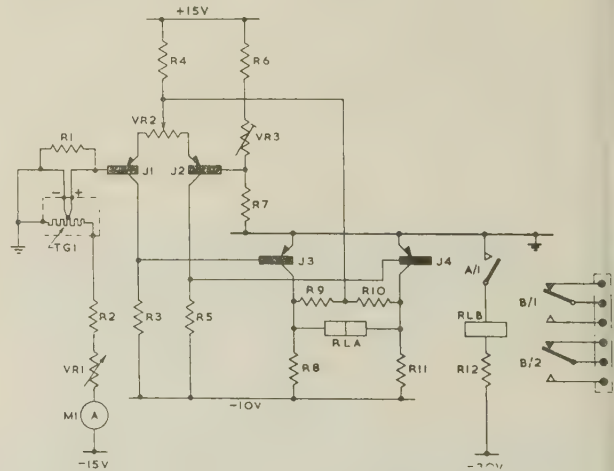


Fig. 5. Circuit diagram of complete assembly.

$R_1 = 100 \Omega$
 $R_2 = 2.2 \text{ k}\Omega$
 $R_3 = 20 \text{ k}\Omega$
 $R_4 = 10 \text{ k}\Omega$
 $R_5 = 20 \text{ k}\Omega$
 $R_6 = 10 \text{ k}\Omega$
 $R_7 = 10 \text{ k}\Omega$
 $R_8 = 2.2 \text{ k}\Omega$
 $R_9 = 15 \text{ k}\Omega$
 $R_{10} = 15 \text{ k}\Omega$
 $R_{11} = 330 \Omega$
 $VR_1 = 1 \text{ k}\Omega$
 $VR_2 = 100 \Omega$
 $VR_3 = 5 \text{ k}\Omega$

$J_1, J_2 = \text{OC201F (Mullard Ltd.)}$
 $J_3, J_4 = \text{OC44 (Mullard Ltd.)}$

$RLA = \text{N29801 A2 (Ericsson Telephones Ltd.)}$

$RLB = \text{SM5A-N96}$

$TG_1 = \text{Thermocouple gauge VC8M (Metropolitan Vickers Ltd.)}$

$M_1 = 0/10 \text{ mA moving coil}$

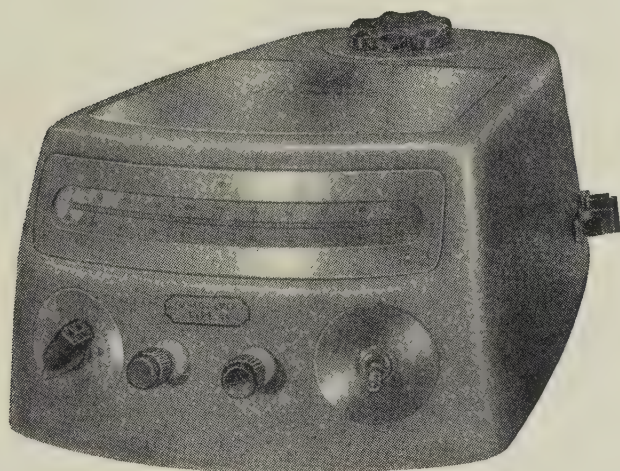


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tched, put in a common thermal junction, and the output
en as a difference signal from the collectors.

Relay stage. The final stage of the unit consists of a
sitive polarized relay driving a slave relay. The polarized

Conclusions

The unit has proved to be very effective, and provided
matched pairs of transistors are used plus a little care in
setting up, it will operate within $10\ \mu$ pressure of its pre-

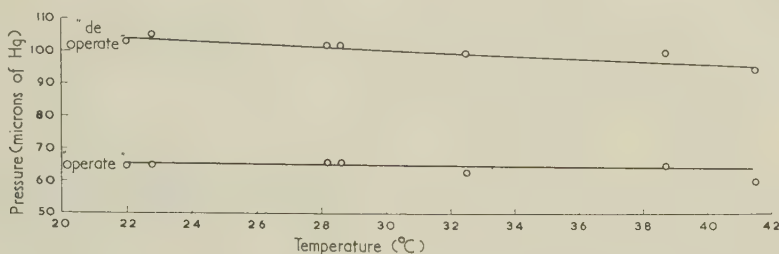


Fig. 6. Variations in 'operate' and 'de-operate' points with temperature.

ay is connected across the collectors of J_3 and J_4 as shown
Fig. 5, which is a circuit diagram of the complete assembly.
is type of relay, the Ericsson N29801A2, was chosen for
high resistance ($5000\ \Omega + 5000\ \Omega$ coils) and sensitivity.
with its coils in series it will operate on $0.5\ \text{mA}$ and being
the polarized type it was expected to have a fairly well-
fined release point. The slave relay was inserted to give a
der choice of contact arrangement and because of its higher
ntact rating.

Tests

Figure 6 shows variation in 'operate' and 'de-operate' points
th temperature. The temperature of the unit was raised
blowing it with a hot air blower, allowing sufficient time
the components to stabilize before taking a reading. It
n be seen that the greatest change in 'operate' or 'de-operate'

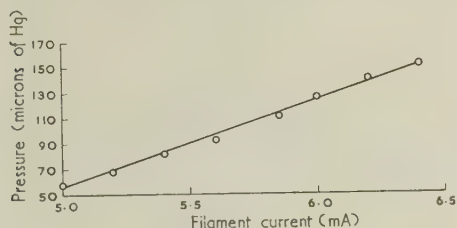


Fig. 7. Variation of operating point with filament current.

oints over $20\ \text{deg C}$ was $10\ \mu$ pressure. This is well within
e stability limits required for most vacuum systems.

It will be seen from Fig. 7, showing operating point plotted
against filament current, that a change in the operating point
to $10\ \mu$ pressure can be effected by changing the filament
current by $0.13\ \text{mA}$ ($\sim 2\%$). For this reason a stabilized
power supply was used. The one chosen here is a standard
E.R.E. type 2015A (Lewis 1959). This is within the
arwell range of Unitized equipment, into which the Vacuum
ip Unit has been built.

Figure 8 is a plot of output against pressure for the thermo-
couple gauge at constant filament current. This graph shows
greater rate of change of output at low pressures and thus
e differential between 'operate' and 'de-operate' points
increases with decreasing pressure. The differential is also
ected by the gain of the transistor, high gains giving low
ferentials.

selected point over long periods. It is economical in use,
as several units can be operated from one power pack.
Total consumption including relays and thermocouple
filament is about $40\ \text{mA}$.

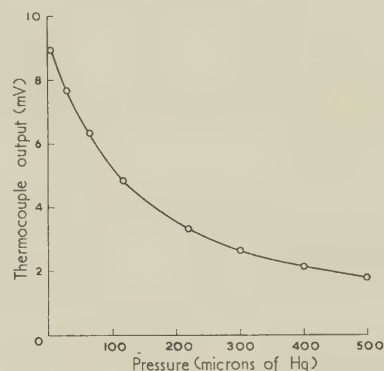


Fig. 8. Variation of output with pressure.

'Fail-to-safety' has been a design consideration throughout,
and the unit will trip to a 'fault' condition if any of the
following occur:

- Power failure;
- Open-circuit thermocouple;
- Open-circuit filament.

By using an ordinary thermocouple the unit could be used
to monitor temperature, performing various functions at
'high' and 'low' points.

Acknowledgments

The author wishes to thank Dr. G. H. Stafford for insti-
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Simple constant-temperature laboratory crystallizer

by B. M. BARTLETT, B.Sc.,* Radiophysics Laboratory, Sydney, Australia

MS. received 25th July 1960, in final form 30th September 1960

Abstract

A description is given of a simple laboratory crystallizer employing a novel centrifugal system for the circulation of solution.

Introduction

A WIDE variety of crystallizers has been designed for growing large single crystals of various materials from solution. All these devices are based on one of the following principles:

- (i) controlled evaporation of a saturated solution;
- (ii) controlled cooling of a saturated solution;
- (iii) continuous circulation whereby solute is dissolved to make a near-saturated solution in one region of the apparatus at one temperature, and deposited on seed crystals in the growing region at a lower constant temperature.

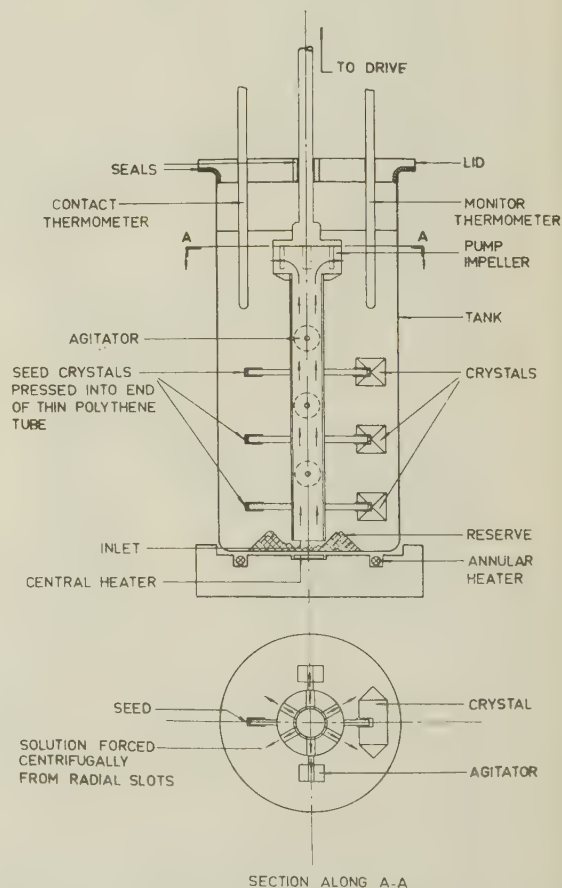
The principles of controlled cooling and continuous circulation are somewhat easier to apply in semi-automatic crystallizers than that of controlled evaporation and are therefore more generally used. Most of the successful present-day equipment using these principles appears to be based on the rotatory-crystallizer design of Holden (controlled cooling) (Holden 1959), or the Walker-Kohman crystallizer (continuous circulation—constant temperature) (Walker and Kohman 1948, Walker 1950).

Circulation of the solution in the Walker-Kohman apparatus results from the use of an external pump, a feature which is not reproduced easily in laboratory-scale apparatus. In contrast, circulation of the solution in the much simpler Holden apparatus depends on natural convection, assisted by the vortex of the rotating 'spider' which holds the growing crystal. The circulation requirements of apparatus for 'constant temperature' operation and for 'slow cooling' are somewhat different. For slow cooling, the main requirement is that the solution should be well mixed; that is, the solution should be maintained homogeneous throughout, both with respect to temperature and to composition, while the whole is being slowly cooled. On the other hand, for constant-temperature operation the solution is warmed and recharged with solute while in the vicinity of the solute reserve on the tank bottom (the logical place for the solute reserve in view of the mode of operation of the crystallizer), and then transferred to the growing region, having been cooled in transit to the growing temperature. It was found from experience that the circulatory flow of solution in a crystallizer closely modelled on the original Holden apparatus was not sufficiently positive for constant-temperature operation. To overcome this difficulty a simple laboratory version of the Walker-Kohman apparatus has been developed in which

circulation is brought about not by convection, but by a centrifugal pump integral with the 'spider' holding crystals.

Description of crystallizer

The crystallizer consists of a glass tank (a modified form beaker of two litres capacity) of solution within which a spider rotates coaxially. The spider carries seed crystals at the ends of one set of radial arms and solution agitators at the ends of another set at right-angles to the first (see the diagram). The solution agitators are necessary to provide adequate mixing of the solution when crystals are small. The spider is a long polystyrene tube with slots machined in a head at upper end, also functions as a centrifugal pump. From the figure it will be seen that, as the spider is rotated, solution



Schematic diagram of crystallizer.

* Now at Division of Electrotechnology, C.S.I.R.O., Sydney, Australia.

forced radially from the slots, causing more solution to be drawn up the tube. In this way, solution is taken from the

bottom of the tank, in the vicinity of the solute reserve, and charged horizontally just below the surface.

The solution tank is mounted firmly on a thick block of thermal-insulating material into which a small concentrated spiral heater and a larger annular heater have been built. The annular heater, which is controlled by a contact thermometer situated a little below the exhaust level of the pump, has low thermal inertia and responds rapidly to variations in solution temperature.

The tank has a flanged lip whose upper surface has been ground flat to accommodate a close-fitting polystyrene lid, which forms a seal with the flange and prevents the escape of water vapour from the system. The rotor axle passes through a neoprene seal in the lid to the drive motor; the lid also supports the contact and solution thermometers.

For a pump of given geometry, the speed of rotation controls the rate at which the solution is pumped; this, in conjunction with the input of heat to the apparatus, determines the degree of supersaturation under which the crystals are grown. Good mixing is achieved by running the spider above 10 rev/min, the direction of rotation being reversed every 20 seconds (approximately). Reversal is necessary to maintain the position of the crystals relative to the mother liquor; otherwise, flaws develop on the trailing faces, even though clear

growth is occurring on the leading faces. It should be noted that pumping takes place irrespective of the direction of rotation of the impeller. From previous work, it was considered that mixing in the present unit was adequate, so that supersaturation could be varied simply by increasing the rotational speed above the 10 rev/min level. Using this apparatus, it was found possible to grow almost flawless crystals of potassium cobalticyanide 4 cm in length from a saturated solution at 33° C in a four-week period.

It is also worth noting that in the Holden crystallizer, variations in the rate of rotation of the spider are, within limits, comparatively unimportant. Here, however, the dual function of the spider requires that the rotational speed be constant to maintain a continuous flow of solution to the growing region, and to preserve a constant distribution of temperature throughout the apparatus. Some care is therefore required in the selection of a motor drive for this purpose.

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Recording integrator for gas chromatography

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Abstract

An automatic integrator is described based on the velodyne principle, whereby a motor is caused to run at a speed proportional to the signal to be integrated. The total number of revolutions of the motor in a given period is proportional to the time integral during this period. The integral is recorded continuously in analogue form on the same chart as the input signal.

The basic units are standard commercial items and relatively simple additional circuitry gives a flexible control system. The accuracy obtainable is of the order 0.5%.

1. Introduction

THE result of an analysis by means of a gas chromatograph is normally recorded on a strip-chart recorder in the form of a series of peaks, the position of the peaks being characteristic of the constituents present and the height of the peaks depending on the individual concentrations. The normal interpretation of such chromatograms in quantitative terms is based on the establishment of a relationship between peak height or peak area and concentration. In practice, measurements of area are frequently more reproducible and exhibit a more linear relationship, and area measurement is therefore widely used. The area measured is the area between the continuous record of the column detector

output and the base-line or time axis of the chart, and the measurement is commonly carried out by methods such as counting squares or using a planimeter.

These methods have several disadvantages; in particular, the fact that they cannot be applied until the analysis has been completely recorded. The measurement is also time-consuming, tedious and lacking in accuracy when small areas are involved.

The measurement of area, in this case, is equivalent to the integration with respect to time of the detector output referred to the base-line as zero, the relationship between area and time integral depending on the chart speed used in making the record. There are various means of performing such an integration simultaneously with the generation of the detector signal, based on mechanical, electromechanical or electronic principles. Considerations of accuracy, reliability, ease of construction and maintenance and cost led to the conclusion that the velocity-servomotor type of integrator, known as the velodyne, was the most suitable type.

If a continuous record of the integral is provided, then the use of this record for analysis overcomes all the disadvantages of area measurement. The integral record is presented instantaneously and can therefore be read out at any stage in the analysis. The integral can be read off the recorder scale and, in the case of simple peaks, the operator is relieved of all other manipulations. An accuracy of measurement

sufficiently high for the smallest peaks to be recorded can be built into the apparatus by suitable design, and the accuracy required has very little influence on cost.

2. General description

Principle. This device is based on the fact that if a motor runs at an angular speed θ_t , which may vary with time, then the total rotation of the motor shaft during the time interval T_1 to T_2 is given by:

$$\Theta = \int_{T_1}^{T_2} \theta_t dt.$$

Thus if the angular speed is made proportional to some desired signal v_t , then the total rotation will be proportional to the time integral of this signal

$$\Theta = K \int_{T_1}^{T_2} v_t dt.$$

In order to perform a measurement of the integral, three main units are required:

- (i) a means of controlling a motor to run at a speed proportional to the input signal;
- (ii) a motor and a means of indicating and recording the total rotation of the shaft;
- (iii) a transducer capable of presenting the input signal in a form suitable for operating the motor controller.

Input transducer. In this equipment the input to the motor controller is obtained from a transmitting slide-wire in the potentiometric recorder used to record the column detector output, the wiper of the slide-wire being driven by the balancing motor of the recorder. This slide-wire is supplied with a potential difference of 20 v derived from the power supply unit in the motor controller. The output from the slide-wire is thus a voltage, which varies linearly with the column detector output in the range 0–20 v.

Motor controller. This unit contains three standard sub-units manufactured by Servomex Controls Ltd. These are an amplifier, its associated power supply unit and a second power unit supplying current to the motor armature. The input to the amplifier has been so designed that a motor speed range of from zero to full speed (6000 rev/min) is obtained for an input signal range of 0–20 v.

An attenuator has been provided so that the motor speed at any input level can be reduced in six steps to one-tenth of the normal speed. Provision has also been made for off-setting the zero so that the motor can be stopped for input signals of up to 3 v in order that non-zero base-lines may be used in the column output detector. This adjustment does not alter the sensitivity of the integrator.

Motor unit. The motor is an Evershed and Vignoles type FAG 2/K4/BDR d.c. servomotor having a d.c. generator built into the same housing. The motor drives a continuously rotatable linear potentiometer *via* a step-down gear ratio of 625 : 1. The potentiometer is supplied with a fixed d.c. voltage and its output is therefore a d.c. voltage, which varies from zero to a maximum value for one rotation of the potentiometer or 625 rotations of the motor shaft. This output voltage is fed *via* a suitable attenuator to a second potentiometric recorder. Full-scale pen travel corresponds to one revolution of the potentiometer and any intermediate position may be read off from the recorder scale.

Recorder. This is a duplex recorder having two inputs to two separate amplifiers driving two pens over a common

chart. One input is taken from the column detector and drives the differential pen, while the second input is obtained from the potentiometer on the motor shaft and drives the integral pen. The chart therefore displays the normal peak record together with a superimposed integral record.

Two separate recorders could be used for the two signals but their time scales must be synchronized. In practice, for all but the simplest peaks, the provision of a common time scale leads to great advantages in the interpretation of the record.

3. Circuit details

General. The complete circuit diagram of the equipment is shown in Fig. 1. The standard units, such as the basic units of the motor controller and the recorder, are shown in block form only and full details are given in the manufacturers' literature. The remainder of the diagram shows the circuits necessary for setting-up and operating the integrator.

Input transducer. The transmitting slide-wire TS receives its power supply from a 350 v source in the main power supply unit, and the slide-wire voltage is adjusted to 20 v by means of the variable resistor RV₁. The value of 20 v was chosen as the highest voltage applicable to a slide-wire having resistance and current-carrying capacity appropriate to the required high resolution. The voltage divider R₁ and R₂ connected across the slide-wire, is such that when the '20 v' switch S₁ is moved to the left it provides an input to the integral pen of the recorder sufficient to produce a known deflection when the slide-wire voltage is exactly 20 v. Thus the setting of the 20 v can be achieved without the use of an external meter.

Motor speed control. The wiper of the slide-wire is mechanically driven by the differential pen of the recorder. It is connected electrically to the comparison circuit R₄ and R₅. This circuit compares the d.c. output voltage V₂ of the generator circuit with the voltage V₁ obtained from the slide-wire, and provides an output at XY which depends on these two voltages. This output forms the input to a high-gain amplifier, the output of which energizes the field coils of the motor M. The armature of this motor is supplied with a constant current from the armature supply unit. Since the motor and generator are mechanically linked, the generator output is proportional to the motor speed and the motor will run at such a speed as to make the output at XY very close to zero. The small signal remaining at balance will be that required to overcome frictional losses in the motor and generator.

At balance

$$V_2 = V_1(R_5/R_4).$$

Now V₂ depends on the generator output and, in the absence of any other voltage source, is proportional to it. Hence the motor speed will be proportional to V₁, i.e. to the position of the differential pen and hence to the signal from the column detector.

The switched attenuator, consisting of the resistors R₆–R₁₀, provides a means of altering the ratio between V₁ and the generator output, and hence determines the ratio between motor speed and input signal.

The switch S₃ is provided in order that a zero input can be provided, independent of the position of the differential pen, for initial balancing of the amplifier.

Bias supply. A 1.5 v dry battery develops a bias voltage across the potentiometer RV₂ when the switch S₂ is closed. This circuit adds an adjustable voltage to the generator

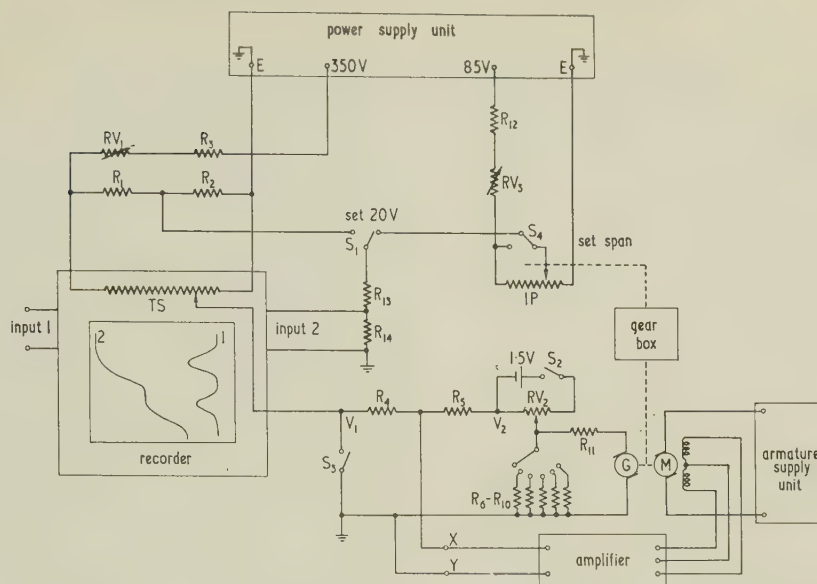


Fig. 1. Circuit diagram of automatic integrator.

$R_1 = 47 \text{ k}\Omega, 1\%$
 $R_2 = 220 \Omega, 1\%$
 $R_3 = 15 \text{ k}\Omega, 1\%$
 $R_4 = 1.33 \text{ m}\Omega, 0.1\%$
 $R_5 = 666 \text{ k}\Omega, 0.1\%$
 $R_6 = 1.111 \text{ k}\Omega, 0.1\%$
 $R_7 = 1.430 \text{ k}\Omega, 0.1\%$
 $R_8 = 2.002 \text{ k}\Omega, 0.1\%$
 $R_9 = 3.430 \text{ k}\Omega, 0.1\%$
 $R_{10} = 10.05 \text{ k}\Omega, 0.1\%$
 $R_{11} = 10 \text{ k}\Omega, 0.1\%$
 $R_{12} = 82 \text{ k}\Omega, 1\%$
 $R_{13} = 47 \text{ k}\Omega, 1\%$
 $R_{14} = 470 \Omega, 1\%$

$RV_1 = 5 \text{ k}\Omega$
 $RV_2 = 500 \Omega$
 $RV_3 = 10 \text{ k}\Omega$

$TS = 1 \text{ k}\Omega$

$IP = 100 \Omega$

M.G. = servo-motor type FAG 2/K4/BDR
(by Evershed and Vignoles Ltd.)

input, and hence, for any given input, the motor will run at a somewhat slower speed so as to maintain V_2 at the correct value. If the bias voltage is V_R the motor will be stationary for an input voltage given by

$$V_1 = V_B(R_4/R_5).$$

In practice, $R_4/R_5 = 2$ so that the maximum bias of 5 v is equivalent to a 3 v bias in the slide-wire output. This feature permits stopping the motor at non-zero inputs up to 3 v, thus giving a zero integral for a non-zero baseline when required. The adjustment is independent of the attenuator setting.

Integral indicator. The motor shaft is connected via a 25:1 step-down gear to the spindle of a continuously rotatable linear potentiometer IP. This potentiometer receives a supply from an 85 v source in the power supply unit and this supply can be adjusted by means of the variable resistor RV_3 . Resistor RV_3 is adjusted so that the maximum output from IP is such as will give full-scale deflection of the integral pen of the recorder, so that one complete rotation of the potentiometer shaft produces one complete traverse of the integral pen across the recorder chart. Operation of the 'set span' switch S_4 allows this adjustment to be made independently of the position of the motor shaft.

In practice, because of difficulties of insulation, the winding of the potentiometer does not cover the full 360° rotation and a gap of about 4° exists between the ends. An allowance must be made for this when setting the span.

The voltage divider R_{13}, R_{14} , is used to reduce the integral signal to a level suitable for the recorder. Use of the divider enables the voltage across the integral potentiometer to be kept at a fairly high level, and thus minimizes the effect of

extraneous signals, such as contact potentials in the switches S_1 and S_4 and the potentiometer wiper.

The choice of the gear ratio between the motor and the integral potentiometer is governed by the speed of the motor corresponding to a full-scale input and the chart speed used in the recorder. For high accuracy a high potentiometer shaft speed is required, but the speed must be sufficiently low for the successive transverse of the integral pen to be resolved when the input is at full scale and the chart drive is the slowest that will be used in practice.

4. Performance

Interpretation and calibration. With no input to the integrator, the integral pen on the duplex recorder will be stationary at a reading depending on the position of the motor shaft. If an input is applied, the integral pen will move at a speed proportional to the input, and when the input is removed the pen will come to rest again. The difference between the two pen positions represents the integral, allowance being made for any complete traverses. Fig. 2 represents a typical record of an analysis showing peaks and the integral trace.

It must be remembered that the integral reading is proportional to the true time integral of the input signal. Thus if the integrator is to be calibrated in terms of area the chart speed must be stated. For most purposes in chromatographic analysis, however, only a means of comparing the integrals is required. In this case calibration may be in terms of arbitrary units, taking the recorder full scale to be one hundred units.

There are other ways in which the position of the motor

shaft may be recorded, apart from the analogue form adopted here. It would be possible, by means of a cam on the motor shaft, to operate a solenoid pen in the recorder to produce a 'pip' on the chart for every revolution and suitable multiple thereof. This does, however, impose on the operator the

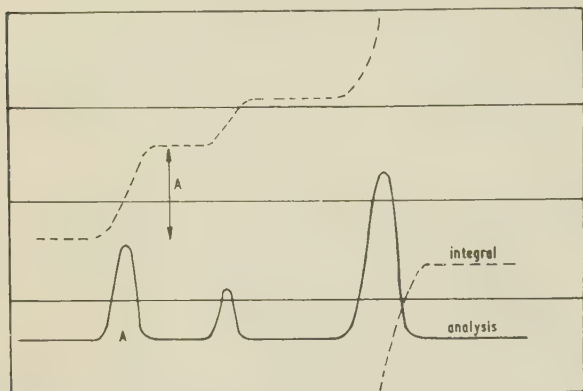


Fig. 2. Typical record of an analysis showing peaks and the integral trace.

task of counting large numbers of 'pips' and there may be difficulties due to lack of resolution at high motor speeds. Alternatively, the measurement of shaft position could be stored in digital form and printed out when required, e.g. at the completion of a peak. However, this requires some means of determining the completion of a peak which requires a stable base-line, and in the case of overlapping peaks will indicate only the sum of the two.

The form of analogue measurement used has been found to be superior in practice, since not only does it give a continuous record during the analysis, but it indicates shaft position and also rate of change. These features are of assistance in the interpretation of complex chromatograms.

Sensitivity. The smallest change in input which will be recorded at the output is governed by the characteristics of the amplifier, motor and recorders. The resolution of the transmitting slide-wire and of the integral potentiometer can be made greater than that of the recorders, so that they do not limit sensitivity. The characteristics of the amplifier and motor are such that the motor will run for a signal input of 0.2% of full scale. This figure is of the same magnitude as the resolution of the recorder, so that provided an input is large enough to be recorded it will cause the motor to run.

However, in order to cause a change in the integral record, the input must be maintained for a time sufficient for the input to the integral pen to change by an amount large enough to be recorded. This amount is again 0.2% of full scale. This means that the integral potentiometer must make 0.2% of one revolution. Since the motor speed will be 0.2% of the maximum (6000 rev/min) the time taken will be the same as that required for one revolution at full speed or 625/6000 min (the gear ratio being 625 : 1). Thus the minimum input must be maintained for 6.25 s.

Resolution. As indicated above, the resolution of the integrator is limited by the resolution of the integral recorder. This is approximately 0.2% of recorder full scale.

Accuracy. The overall accuracy of the integration depends on the accuracy of a number of units, and their contributions may best be considered in two groups—speed control and integral indication.

The error in the relationship between input signal and motor speed arises from three sources, the recorder (0.2% full-scale deflection), the slide-wire supply voltage (0.1% f.s.d.) and the instability of motor characteristics (0.1% f.s.d.). The total error is therefore of the order of 0.4% expressed in terms of full-scale input. If the integrator is calibrated in terms of the area under the differential record, then the error may be expected to be 0.2% only, since the recorder error is not involved. If the motor speed is measured by a method of high accuracy, such as by timing a number of revolutions, then an accuracy of this order is found.

The measurement of the integral is obtained by counting the number of revolutions of the integral potentiometer; this is, by counting the number of traverses of the integral pen and determining the extent of an incomplete revolution by using the recorder scale. No error is introduced by counting complete traverses and the accuracy of the reading of an incomplete traverse is determined by the accuracy of the recorder (0.2% f.s.d.) and of the supply to the integral potentiometer (0.1% f.s.d.). Thus the total error in the indication of an incomplete traverse is 0.3% of the integral represented by a complete traverse. For any given integral the percentage error of the indication depends on the number of traverses.

The precise specification of accuracy is therefore complex because not only does it depend on the magnitude of the integral but also on the way in which the integral is produced. For example, a given integral produced by a full-scale input of short duration will have an error less than that of the same integral produced by a low input of long duration.

A large number of measurements have shown that any given integral may be expected to be accurate to within 0.5% of the integral or 0.5% of recorder full scale, whichever is greater.

Reproducibility. Readings have been found to be reproducible to within 0.5% of the integral or 0.5% of recorder full scale, whichever is greater.

5. Conclusions

An automatic method of integration gives several advantages over manual methods, and use of the velodyne principle yields a robust device having an accuracy which is adequate for most purposes. The motor controller is constructed from standard commercial units, and relatively simple additional circuitry gives a flexible system of adjustment of operating conditions.

The fact that the integral is recorded continuously in analogue form on the same chart as the output of the column detector gives advantages in the interpretation of complex records as compared with methods of digital recording.

Applications of the integrator are not limited to gas chromatography, since it may be used to integrate any signal which is in a form suitable for connection to a potentiometric recorder.

Acknowledgments

The original suggestion of the use of the velodyne principle to achieve the required integration was made by Mr. R. C. Steel, of Servomex Controls Ltd. The author acknowledges the assistance in construction of the equipment of Mr. P. J. Abel, Mr. E. G. Barrow and Mr. R. Sullivan, all of the Distillers Company Ltd.

Improved manufacturing technique for blood-flow probes

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MS. received 20th October 1960

Improved technique for the reliable manufacture of small thermocouple needles as described by Mowbray (1959) has been developed to estimate changes in blood-flow in tissues (McPherson, Scales and Gordon 1961). The manufacturing 'scrap-rate' has been almost eliminated and this is attributed to the careful retention of the original insulating enamel together with the use of Cold-Cure Silastomer rubber (Dowland Silicones Ltd.) as an insulating and moulding material.

The thermocouple assemblies were prepared by placing small lengths of constantan wire (J in the Figure) on a strip of double-sided adhesive tape positioned horizontally across an inclined board. Thermojunction positions for any number of probes were located against background guide lines, and were prepared by removing the minimum amount

of enamel at the specific points indicated by the guide lines. With the aid of a $\times 10$ binocular microscope, it was possible to remove discrete areas from diametrically opposite sides of 40 s.w.g. (0.0048 in.) wire. Enamel-free* tips of the 47 s.w.g. (0.0020 in.) copper lead wires H were then positioned on the tape adjacent to the thermojunction positions on the constantan wire and the junctions were soldered using the techniques described by Mowbray (1959). A simple continuity and resistance check was made on each wired assembly at this stage.

The probe casings G were made from hypodermic-needle tubing and prepared in batches by cutting them to length, bevelling them and soldering on the earth terminal lead D. The head end was then sandblasted, chemically cleaned, primed and together with the remaining three prepared terminal leads A, B and C placed in a simple multi-position mould. The catalysed rubber solution was then poured into the mould and cured to form the silicone rubber head F.

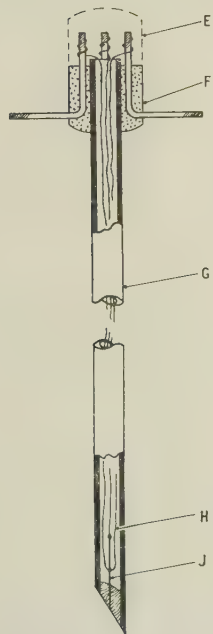
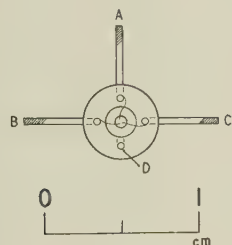
Assembly of the thermocouple wiring to the case may be accomplished in several ways and is largely dependent on the size of the lower thermocouple and heater junction relative to the bore diameter. One satisfactory method was to apply a thin coat of catalysed rubber to the wired assembly, to allow this to cure, forming an insulating sheath and then to insert the coated wires (suitably identified) through the tubing from the bevelled end. Another method was, with the aid of a draw wire butt-jointed to the tip of the constantan wire, to draw an uncoated assembly down from the head end through a pool of catalysed liquid rubber nesting between the vertical terminal wires A, B, C and D. An insulation check was made before soldering the constantan tip to the case. The copper lead wires were then bound round their appropriate terminal wires but, before soldering, care was taken to ensure that they were sufficiently slack to accommodate the effect of any external flexing of the terminal wires.

The probes were finally completed by cleaning up the bevel end on an oilstone and by sealing the head connections with a further application of silicone rubber E.

McPHERSON, A., SCALES, J. T., and GORDON, L., *J. Bone and Joint Surg.*, 1961, in the press.

MOWBRA, J. F., 1959, *J. Appl. Phys.*, **14**, 647.

* A suitable stripping agent is a 1% solution of concentrated hydrochloric acid in ethyl acetate.



Improved blood-flow probe.

A, B, thermocouple terminal wire; C, heater terminal wire; D, casing terminal wire; E, silicone rubber; F, moulded silicone rubber head; G, probe case; H, three copper leads; J, constantan wire.

Simple mercury expansion regulator for control of air temperatures to ± 0.02 deg C

by K. L. BUTCHER, B.Sc., F.R.I.C., M.I.Chem.E., and
M. J. BYRNE, B.Sc., Houldsworth School of Applied
Science, University of Leeds

MS. received 29th September 1960

It has been found necessary to control the environment of a large calorimeter to ± 0.02 deg C at 25–30° C. To this end the apparatus is enclosed in an air bath consisting of a 4 ft square box of $\frac{3}{4}$ in. fibre insulation board mounted on a Dexion frame. The box is raised 1½ ft above the floor level in a room thermostatically controlled to ± 0.15 ° C at 23° C. Vigorous air circulation within the box is maintained by a 5½ in. propeller, driven at 3000 rev/min by a 50 w electric motor mounted outside, clear of the box wall. The control heater, situated immediately in front of the propeller in a

corner of the box, consists of 40 ft of Kanthal heater wire (total resistance 430 Ω) wound on a light asbestos frame, 12 in. $\times$ 14 in. (Kanthal D ribbon—A. B. Kanthal, Hallstammar, Sweden).

A slightly modified version of the electronic controller of Beament and Machin (1959), using a type F 13 thermistor as detector, has been used as thermoregulator. The rectified h.t. lines in the circuit of this controller are not voltage

A commercial electronic thermoregulator with a claimed control of $\pm 0.01^\circ\text{C}$, using a 200 Ω resistance thermometer as detector, suffered from similar disadvantages with systematic drifts of the control region of up to 0.05°C . In view of the limitations of these electronic controllers the following simple mercury-in-steel expansion regulator has been constructed.

The regulator body (see the Figure) is basically a U-tube consisting of 3 ft of $\frac{1}{4}$ in. light mild steel tubing (i.e. $\frac{1}{4}$ in. nominal bore, $\frac{3}{8}$ in. outer diameter, 15 s.w.g. as per British standard specification 1387, 1957), filled with mercury. The arms of the U-tube each have two $\frac{1}{2}$ in. fins of 16 s.w.g. copper sheet, 15 in. long, soft-soldered to them to increase the surface area and thus compensate for the low surface coefficient in air. The glass contact head is cemented into the steel tube with Araldite 103. The other end of the tube terminates in a $\frac{3}{8}$ in. B.S.F. nut welded to it with steel rod. The level of mercury in the regulator is adjusted by manipulating a 3 in. bolt, a locknut, washer and sealing compound preventing leakage of mercury. The regulator is supported from the 16 s.w.g. cross bracket by a clamp and stand. If use it is placed about 14 in. in front of the control heater on one side of the air bath. A 40 w bulb is used with a Variac transformer as permanent background heater within the box and the expansion regulator operates the control heater by means of the Gallenkamp microwatt relay, Cat. No. 12214/3.

After the initial equilibration period this regulator is capable of stable control over long periods, with a mean deviation of $\pm 0.02^\circ\text{C}$ from the mean control temperature as measured by a 20 Ω interval platinum resistance thermometer. The period of one complete temperature cycle is about two minutes.

In the past the accurate control of air temperatures has generally been obtained by using ether vapour regulators (Green and Loring 1940, Yee 1943). It would appear that a simple all-mercury expansion regulator of the type described above is capable of equal, if not more accurate, control and has the merits of simplicity of construction and small bulk.

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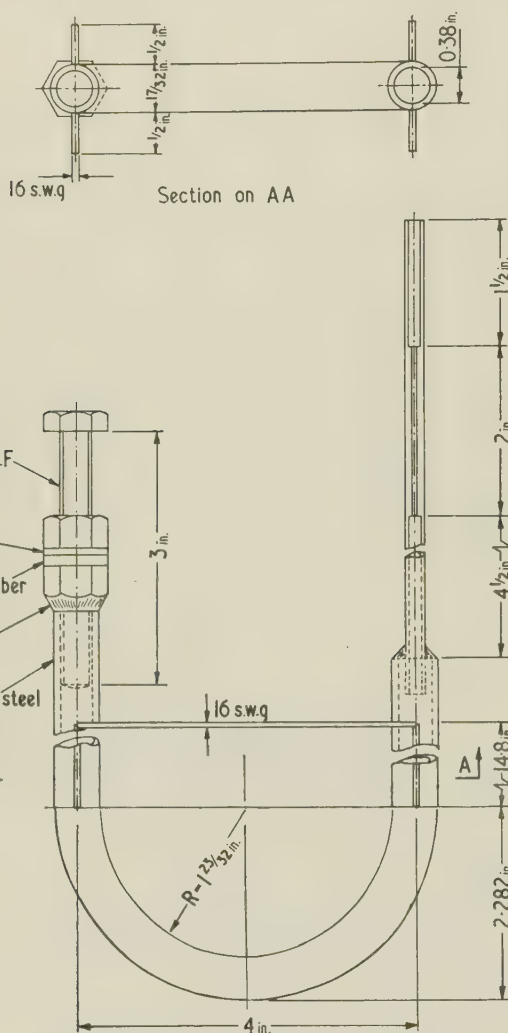
Modification to the model 540 scanning count integrator

by E. MARINIANSKY, B.Sc., E.E., Health Physics Department, Israel Atomic Energy Commission Laboratories, Rehovoth, Israel

MS. received 2nd August 1960, in final form 8th October 1960

The model 540 scanning count integrator (made by Baird Atomic Inc.) programmes the sequence of operations of a single-channel scintillation spectrometer. It produces the histogram plot of a radio-isotope spectrum, but lacks the possibility to stop the sequence automatically (if desired) after one spectrum cycle of one hundred channels is recorded.

This can be overcome by a small modification, namely the addition of several resistors and the use of some partially utilized components included in the instrument. The change may be carried out easily without influencing the accuracy of the instrument.



Mercury-in-steel thermoregulator.

stabilized, however, and the temperature limits for on-off control are found to fluctuate slowly by as much as 1 to 2 deg C here at Leeds, in accordance with changes in the mains voltage.

At the suggestion of Dr. Beament, a type 85A2 voltage reference tube has been incorporated in the negative h.t. line. This effects considerable improvement on the controller performance. In the final version of the instrument, with two type 85A2 tubes on the negative h.t. line and one type 150C4 voltage stabilizer tube on the positive line, and with power supplied from a constant voltage transformer, the wandering of the temperature control limits is not more than 0.06°C during the three-hour afternoon period of maximum daytime mains stability (236 to 240 v).

pulses obtained from the scintillation probe which satisfy 'window' setting of the single-channel analyser are counted by the scanning count integrator during a pre-determined time. At the conclusion of this period, the total count is automatically registered on a recorder. Then the base-line control is advanced one volt while the paper on the recorder is advanced one unit, and the integrator proceeds

consists of the utilization of this period of discontinuity, by stopping the glow of the Dekatron at position No. 6 and thus cutting off the sequence operation.

Valve V 309 and relay K 303 are originally included in the instrument. Valve V 309 B and contacts No. 4 and 5 of K 303 were not used (see Figs 1-2). Normally, V 309 A is cut-off and V 309 B is conducting. When the helipot

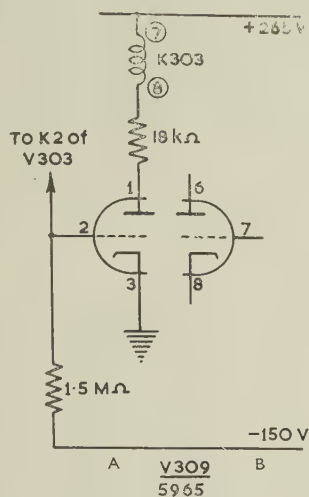


Fig. 1. Control circuit before the change.

count the next channel. The final spectrum is achieved after the counting of the hundred channels. The operations involved include the changing of the base-line voltage by one volt (one step); the advancing of the recorder's paper; clearing of the integrating capacitor; and the duration

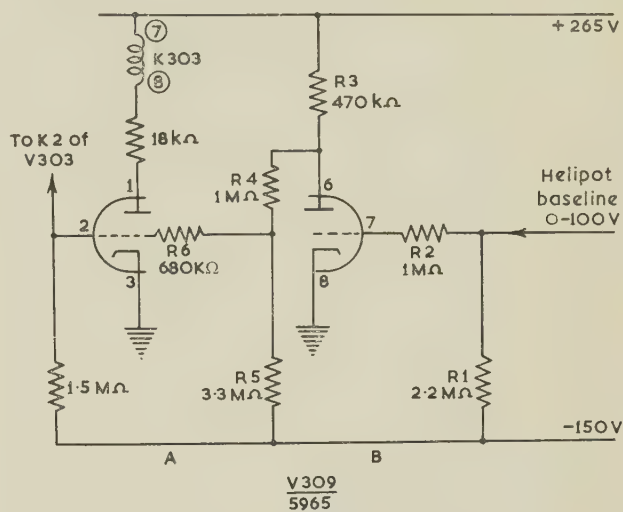


Fig. 3. Control circuit after the change.

potentiometer reaches channel 100, the -150 v are applied through resistors R_1 and R_2 to valve V 309 B and will bring it to a cut-off position (see Fig. 3). The positive voltage applied now to V 309 A will energize relay K 303 and the short between pins 4 and 5 of this relay is removed. As a result the clock pulses cannot draw the glow from the cathode

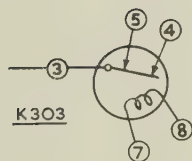
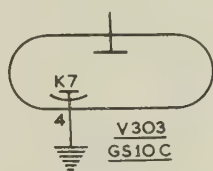


Fig. 2. Control steps before the change.

the counting period. They are all governed by a Dekatron tube (V 303-type GS 10 C) activated by clock pulses generated by the instrument.

The advancing of the base-line potentiometer is carried out by a motor, activated when the glow of the Dekatron tube reaches position No. 2. One full rotation of the helipot base-line potentiometer consists of one hundred steps. The electrical rotation covers only 356° , thus providing a discontinuity, so that the last channel, No. 100, disconnects the slider from the voltage divider. The suggested change

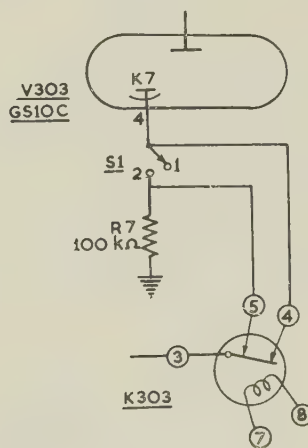


Fig. 4. Control steps after the change.

No. 6 of Dekatron tube V 303 and the sequence is stopped (Fig. 4).

The added switch S_1 being in position 2 operates the instrument continuously by avoiding the disconnection between pins 4 and 5 during the 'channel No. 100' period.

Thanks are due to Mr. J. Sheinin for his assistance.

Welding of conducting electrodes to thin metallic films

by ST. DEMBICKA-JELLONKOWA, Wrocław Institute of Technology, Wrocław, Poland

MS. received 23rd September 1960

The method of measurement by means of a four-point probe, formerly used for the measurement of the resistance of semi-conductors (Valdes 1954), was applied in the study of the electric resistance of thin metallic films (Dembicka-Jellonkowa, to be published). In this method the current enters and leaves by two thorn-shaped electrodes, while the voltage drop is measured with a potentiometer between a pair of additional electrodes, placed between the current electrodes. An instrument of this kind has proved to be a very convenient device in studies of thin silver films, but when applied to the measurement of thin chromium films, less than $1000 \text{ \AA}$ in thickness, the contact between the electrodes and the metal of the sample was uncertain and unstable. This made it difficult to carry out the measurements correctly, as they required a stabilization of the current value, at least for the period of a single potentiometric measurement, and also, if possible, for a period of several successive measurements carried out as checking examinations. This difficulty was removed by welding the electrode to the film, using a suitable current pulse. The pulse was introduced to the current circuit of the probe either inductively, by breaking the current in the primary winding of the transformer series connected to the probe by its secondary winding, or by discharging a capacitor previously charged from an auxiliary source of constant voltage. During attempts to adjust the most convenient capacitance and voltage, an improvement in contact was noticed even with an applied voltage of 10 v or more at a capacitance of $0.5 \mu\text{F}$. Contact was ensured by discharging a $0.1 \mu\text{F}$ capacitor previously charged at 70 to 100 v , while a voltage of 150 and a capacitance of $0.1 \mu\text{F}$ damaged the film near the contact, and caused a break in the current flow. The range of working conditions needed to ensure contact, but not damage the film, is thus sufficiently wide for the welding method to be conveniently used in practice. Under the given conditions chromium films from about 80 to $1000 \text{ \AA}$ in thickness were welded satisfactorily. The welding method is easier and more convenient than other methods used to prepare electrodes to contact with thin films. The most commonly used methods have been pressed electrodes, metallic films burnt into the base, thermally sprayed contacts (Godziński and Dembicka-Jellonkowa 1955), and connections soldered with indium (Belsér 1954). These methods had many disadvantages: electrodes could only be placed in a constant position and could have only a rather loosely defined contact boundary with the sample; their preparation required skill on the part of the worker, particularly if the film was thin and easily damaged. In contrast to the above, optimum conditions can easily be established in the welding method: it can then be carried out very quickly and at any point of the sample, the place of contact being exactly determined. The welding of contacts combined with the use of thorn electrodes may considerably facilitate the work in the case of thin films, where contact with electrodes has so far been difficult or uncertain.

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VALDES, L. B., 1954, *Proc. Inst. Radio Engrs*, **42**, 420.

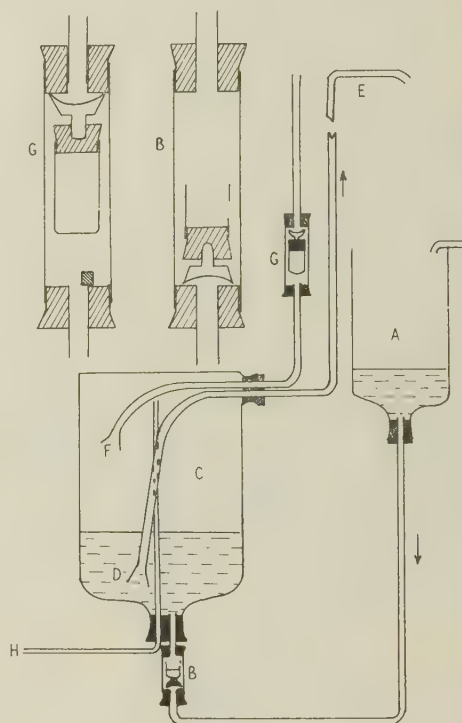
Simple circulating pump

by A. MACFADYEN, Department of Zoology, University College of Swansea

MS. received 28th September 1960, in final form 26th October 1960

There is often a demand in biological laboratories for a reliable circulating pump without metal parts, which can handle a few litres of water a minute. Examples are the circulation of sea water and culture media and external cooling of water baths by refrigerated water.

This need can be met by modern plastic electric pumps but these are costly, far from silent, and perhaps not reliable.



Circulating pump.

enough for operation over many months. The pump described here operates from compressed air and meets the above specification at a cost of under £5. The parts are normal laboratory stock and the whole can be assembled in a few hours.

A five-litre aspirator is fitted with bungs and glass tubing as shown. Water returning from circulation collects in (cut down Winchester bottle), and passes by the foot valve to the aspirator C. Compressed air is supplied continuously through H and escapes via F and G. When the water level rises D and then F are filled. The compressed air forces water up the tubes leading to G and E, but since the float in G now blocks the escape of water it can only leave C the way of E. From E it passes to a storage tank and then circulates back to A. When C is empty the compressed air escapes through E because D is momentarily above the water level; this allows the float in G to fall and air to escape once more through F. The aspirator now fills through the foot valve B which has blocked the entry of water during the pumping part of the cycle.

few practical points concern the valves and the openings and D. The former consist of rubber suction cups sold on bows in children's archery sets (see inset) which press against a rubber bung. The float in G is a glass specimen weighing so that it just floats, and sealed with black paint. The tubes ending at F and D consist of funnels supported on a flexible length of rubber; the weight of water when the funnels are full keeps their openings down but when air enters, the rubber makes them spring up and vents bubbles of air and water entering the tubes. The angle between F and G should slope so that it drains during the pumping period and G should be placed quite close to C. For rates up to 2 l./min and a useful head of 1 m, tubing should be of 1 cm bore. The pump operates reliably over a range of from 30–90 lb/in.² (2–6 kg/cm²) pressure and the very little maintenance required over several years' use has been replaced by perished rubber tubing.

Device for preparing accurately X-ray oriented crystals

by W. L. BOND, M.Sc., Bell Telephone Laboratories,
Murray Hill, New Jersey

MS. received 26th July 1960

The combination orienting-grinding device described here will produce surfaces accurate to about two minutes of arc in plate angles that are within five degrees of proper orientation. With the help of the auxiliary device described, one can produce surfaces of two-minute precision from any crystals whatsoever. The procedure is as follows.

The crystal blank is waxed (hot) to the flat end of the stem, Fig. 1. The stem is then slid into the shell. Here the leaf

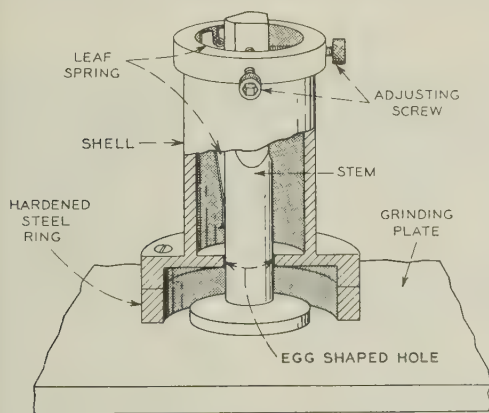


Fig. 1. Cut-away view of the grinding operation.

spring forces the stem into the small end of the egg-shaped hole and also forces the upper end of the stem against the adjusting screws, which are at right-angles. The shell is now placed in the V-block of the x-ray orienting goniometer, Fig. 2. With the x-ray detector set at the proper double Bragg angle, the goniometer arm is swung slowly to find the x-ray reflection. When the x-ray reflection has been found, the scale reading is noted and the shell turned through 180° around its own axis in the V-block and the reflection again noted. If the requirement is to grind parallel to this plane, the proper adjusting screw is turned to move the x-ray reflection at a goniometer arm-scale reading which is the mean of the two noted readings. Having accomplished

this, the shell is turned through 90°, and the second screw is adjusted to the required precision in the same manner. If the requirement is to produce a plane at an angle α to some atomic plane, one screw adjustment is so made that the difference between the two scale readings for the zero and 180° position of the shell is 2α .

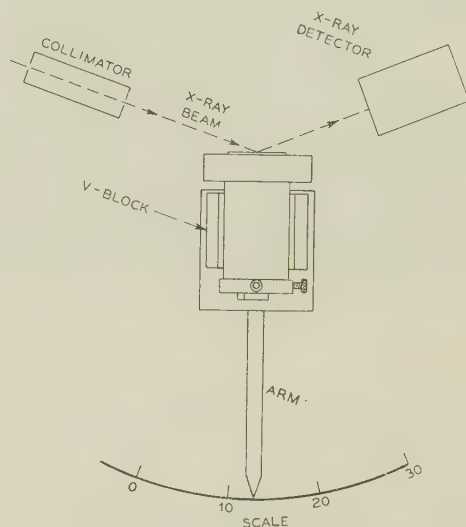


Fig. 2. The x-ray goniometer.

With the adjustment completed, the stem may now be slid slightly back or forth in the shell until only a little of the crystal projects beyond the hardened-steel ring. The shell is now moved about on a lapping plate covered with wet abrasive (such as silicon carbide). This grinds away the crystal until it is flush with the steel. If the crystal still needs grinding, the stem is slid out a little more and the grinding is carried on until inspection shows it to be satisfactory. A piece could be made to clip on to the upper end of the shell and provide a screw adjustment for this sliding motion, but we have not found it necessary.

For producing oriented plate edges, a second stem is used that presents the edge of the crystal to the grinding plate.

The hardened-steel ring has two merits: it wears much longer than does a soft-steel ring and, when use has rendered the ring untrue, it is easily taken off the shell and reground on a surface grinder. The shell we use has a diameter of 1½ in. for the part that contacts the V-block, this cylindrical portion being 2¼ in. long. The stem diameter is ⅝ in. and the diameter of the hardened ring is 2½ in. o.d., 2 in. i.d. The stem has three flat areas milled into the small end: two at right angles

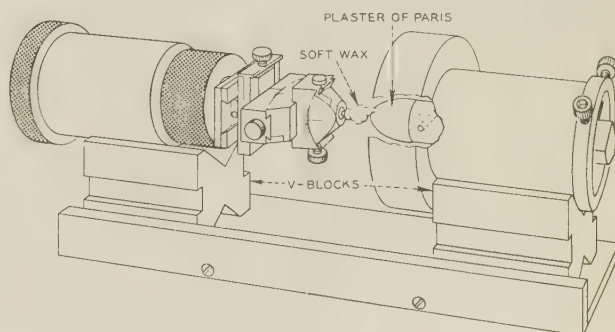


Fig. 3. Transferring the crystal.

to each other give the adjusting screws a seat; the third, which is at 45° to the first two, is the spring contact area. Without this flat area, the stem could rotate slightly relative to the shell, which would reduce the accuracy of the device. The spring is a clock spring, 0.040 in. thick and $\frac{1}{2}$ in. wide.

If the crystal blank is not within 5° of the desired orientation, it is mounted on a goniometer head using cheese wax (Candy Company, Chicago, Illinois), the approximate orientation being judged from existing crystal faces, cleavage traces, extinction directions, etc. The head is screwed on to a $1\frac{1}{2}$ in. diameter cylinder and placed in the goniometer V-block. The goniometer head is adjusted to give the proper x-ray reflections at the proper readings of the scale. Then the crystal is transferred to the shell holder. This is done in the apparatus shown in Fig. 3. This consists of two V-blocks resting on a cold rolled-steel plate which has a guide edge strip which holds the V-blocks in line. One V-block supports the goniometer head, the other, the shell holder. Some

freshly mixed dental plaster is placed on the end of the stem and the shell assembly is slid along the guide edge until the crystal is partly buried in plaster. If mixed not too wet, the plaster sets in about five minutes. When the V-blocks are pulled apart, the crystal is left in the plaster. The shell adjusting screws can be corrected in the goniometer and the flat surface ground on to the crystal as before. For this use the stem end has a few holes to engage the plaster since it will not adhere to smooth steel.

If there are no faces on the crystal and no indication such as cleavage, optic axes, etc., the crystal is stuck into the cheese wax at random and a systematic search for an x-ray reflection is made. Upon finding a reflection, the crystal and plane normal are roughly sketched. Then another plane is sought using the first plane as a guide. Knowing two plane normals one may deduce the rest, except in certain cases when an ambiguity remains which may be resolved by checking a third plane.

CORRESPONDENCE

Daylight factor meter

Since the publication in this *Journal* of my paper, *Daylight Factor Meter* (Turner 1960), it has come to my notice, in correspondence, that a description by W. Koch, M.D., Ph.D., and D. Kaplan, M.Sc., Ph.D., of a daylight factor meter operating on the same basic principle of simultaneous comparison in a bridge circuit of the output of two photoelectric cells was published in the same *Journal* in 1952.

Products Application Laboratory,
Pilkington Brothers Ltd.,
St. Helens,
Lancashire.

Despite the differences of design detail between the two instruments it would have been of considerable advantage to me to have seen the paper by Dr. Koch and Dr. Kaplan before now and my sincere apologies are due to these authors for failing to do so and to make proper recognition of their work in the account of my own.

D. P. TURNER
16th November 1960

KOCH, W., and KAPLAN, D., 1952, *J. Sci. Instrum.*, **29**, 179.
TURNER, D. P., 1960, *J. Sci. Instrum.*, **37**, 316.

New instruments, materials and tools

Editor invites manufacturers of instruments and light sensitive materials to keep her informed of their new or improved products. The Institute of Physics and the Physical Society assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

Radiographic apparatus. Watson and Sons (Electro-Medical) Ltd., Industrial Division, East Lane, North Wembley, Middlesex.

The apparatus, which is manufactured by Rank-Xerox Ltd., can be used to produce an industrial radiograph in 15 seconds.



Fig. 1.

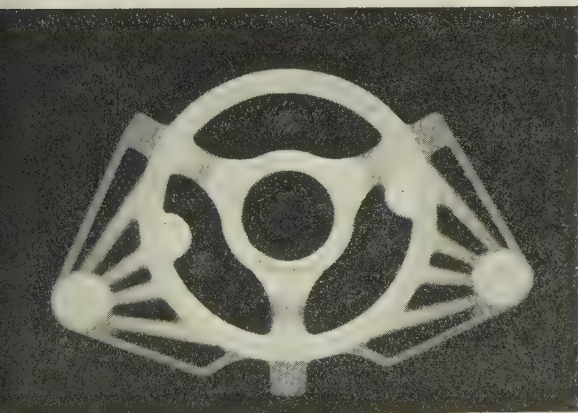


Fig. 2.

This is done by means of the xerographic process which is a dry process and no chemicals or darkroom is needed. It is a feature of this process that image contrast is increased at sharp boundaries and for small cracks, pinholes, etc. The overall contrast is, however, low and a large range of thicknesses can be accommodated in one exposure. The resolution of the plates is said to compare favourably with medium speed non-screen industrial x-ray film and requires about the same exposure. Conventional x-ray apparatus is used.

The plate has a sensitive area of 13 in. $\times$ 8½ in. and its average life is about 1000 exposures. A 35 mm camera is incorporated in the apparatus and may be used to make a permanent record of the image.

Pocket pH meter. Cambridge Instrument Company Ltd., 13 Grosvenor Place, London, S.W.1.

This instrument, which weighs less than 3 lb, has a scale covering the whole pH range from 0 to 14 units and is calibrated in divisions of 0.2 pH. Accuracy is to ± 0.1 pH and the reference and measuring electrodes are combined into a single concentric unit which is not seriously affected by the presence of sodium ions in the range above 10 pH.

The instrument is powered by dry cell batteries with a life of approximately 1000 hours. It can be supplied with a plastic shoulder strap carrying case which has an extra compartment for the electrode and buffer solutions.

Millimicrosecond pulse generator model 120B. Livingston Laboratories Ltd., Retcar Street, London, N.19.

Designed for performance testing of high speed pulse circuits and components the model 120B pulse generator made by Livingston Laboratories Limited provides variable width pulses having a very fast rise time and a high repetition rate. Two separate outputs are provided on the front panel, each giving pulses with a rise time of less than 2.5 mμsec at repetition frequencies from 10 c/s to 10 Mc/s, the outputs being independently variable in amplitude from 0 to -8 v and pulse width between 2.5 and 25 mμsec.

It is also possible for the generator to be driven externally and provision is made for external gating and for single pulse operation, whilst a 15 v trigger output is available to initiate timing cycles or to trigger an oscilloscope.

New books

The cathode ray tube memory of the high-speed electronic computer of the U.S.S.R. Academy of Sciences. By V. N. LAUT and L. A. LYUBOVICH. (London, Oxford, New York, Paris: Pergamon Press, 1960.) Pp. xii + 90. 35s.

In the early period of computing machine development a number of solutions to the problem of immediate access storage were suggested. The 'Selectron' was soon abandoned and, in this country and in the U.S.A., the Williams tube store enjoyed a short period of use. The initial advantage of this system was that it used standard cathode-ray tubes, but this was accompanied by corresponding disadvantages due to basic unsuitability. The third method suggested was to construct a special purpose, but comparatively simple, barrier grid tube by which regeneration problems were automatically simplified. Such tubes were designed in the U.S.A., but never enjoyed wide popularity, at least in the computer field.

The Russians, however, produced a suitable tube, the LN-1 'Potentialscope', and have used it as the high-speed store of the BESM computer; the present book describes in turn the construction of the 'Potentialscope' tube, the circuits for reading and writing in each channel of storage, and the deflection system used to produce the storage raster. These preliminaries are followed by an account of the overall control circuits of the storage unit and of the way in which this unit is connected with BESM.

Finally there are details of the test procedures used on the storage unit, an account of the structural design and a discussion of operating experience and future prospects.

There is no indication of the date of the Russian edition of the book, but internal evidence suggests 1956-1958, since it appears that no ferrite core store was operating in the U.S.S.R. at the time of writing. The authors, even so, expressed the feeling that the 'Potentialscope' would be replaced as soon as possible and this has now been done

in recent machines. As a *record* of Soviet work, however, this book will be of great interest to Western computer engineers and physicists. It is well translated and can be thoroughly recommended.

A. D. BOOTH

Flame Photometry. By J. A. DEAN. (New York, Toronto, London: McGraw-Hill, 1960.) Pp. viii + 354. 89s.

Flame photometry is at first sight a simple technique: solution is sprayed into a flame and the spectrum of the light emitted is observed. Intensity of a line emitted by an element is a measure of the concentration of that element in the dissolved material. However, the intensity is affected by other factors.

Chemical interferences occur—the presence of other elements may affect the dissociation of the material, or may inhibit ionization after dissociation has occurred—for example potassium may enhance the emission of sodium, and vice versa. The intensity of a line may be enhanced by the presence of organic material, and in fact organic solvents are often deliberately added to produce enhancement. The background emission on which the line emission is superimposed may vary, and even if constant it lowers sensitivity. In connection with the solution which is sprayed, variations in droplet size, surface tension and viscosity have to be considered. When the drop has dried in the flame, the resulting grain of solid must be volatilized sufficiently rapidly for its presence in the flame is transient, so that variation of boiling points with composition is important.

It is not surprising that this is the fourth full-length treatise on the subject to appear in the last six years (the publisher's blurb hails it as the first). It is a useful compilation and the chapter on the effect of adding organic solvents is valuable. The bibliography is extensive, and contains some references as late as 1959. A brief account of atomic absorption spectroscopy is included.

A. C. MENZIES

Notes and comments

Craftsmanship and Draughtsmanship Competition

The Craftsmanship and Draughtsmanship Competition of the Physical Society is continuing in the same form as in the past and after the present Competition arrangements have been in the hands of the Education Committee of The Institute of Physics and The Physical Society. The number of entries to the Competition this year has been disappointingly small but the standard of entry has been maintained and indeed is better than that of the previous year.

The Classes into which the Competition is divided are:—

- II. Scientific Instruments and Components
- III. Optical Components and Systems
- IV. Blown-glass and Silica Ware
- V. Instructional Items and Models
- VII. Microwave Components
- VIII. Electronic Circuitry

There is also the Silvanus P. Thompson Prize (Class I) which is awarded for an exhibit together with corresponding working drawings.

In each Class there is a possibility of obtaining a first, second or third prize or a Certificate of Honourable Mention. Besides these there has recently been instituted a Certificate of Merit which is awarded to all exhibits which are worthy of display at the Annual Exhibition of Scientific Instruments and Apparatus although not quite reaching the standard required for a Certificate of Honourable Mention. The first prizes in the Classes for Scientific Instruments and Components, Optical Components and Systems and Instructional Items and Models were again Bowen Prizes, presented by the Scientific Instrument Manufacturers' Association from the Bowen Trust Fund.

In Class II the judges comment that 'all the entries were of a very high standard and there was a notable absence of minor faults and errors of craftsmanship which had marred otherwise creditable entries in previous years.' As a result of this the margin between items which received awards and those which did not was extremely narrow. The judges recommended that every entry which did not receive a first prize or a Certificate of Honourable Mention should be awarded a Certificate of Merit.

In Class III there were only four entrants but all obtained an award. The first prize was adjudged an excellent piece of technical work, showing skill of a very high order, and the second prizewinner was also complimented on an excellent piece of workmanship.

Eight out of the nine entrants in Class IV obtained awards and the general report of the judges was that the work was very well and carefully executed.

The entrants in Class V were again all adjudged worthy of an award. Of particular interest was a reproduction of a Sixteenth-Century Assayer's Balance. This was made under the Science Museum's scheme for setting up a Historical Collection: the notice of firms who participate in our Craftsmanship Competition was drawn to the Science Museum's need for reproductions of early pieces of apparatus for their Historical Section and it was arranged that any suitable for the Institute and Society's Competition might be included.

This Sixteenth-Century Assayer's Balance was of excellent craftsmanship and was awarded a special prize.

It was disappointing that there were not more entries in Class VII, Microwave Components, although those submitted were in general of good standard.

In Class VIII, Electronic Circuitry, there were a few more entries this year but the judges were disappointed that there were not more. Some of the work was not of as high a standard as might be hoped but the first and second prizes in each section showed particularly thorough workmanship. Two of the entrants (first and third prizes in Class VIIIa) were considered eminently suitable for training purposes and the judges commended this type of entry as most appropriate to the Junior Grade of this Class.

The Silvanus P. Thompson Prize, which readers will remember is awarded from a Fund set up by the City and Guilds Institute in memory of Silvanus P. Thompson, is awarded for a combination of draughtsmanship and craftsmanship and the prizewinner in this Class was also awarded first prize in the Scientific Instruments Class. There were only three entrants for this prize; it is hoped that firms will encourage more entrants to this Class and also to Class VI which is for younger entrants who wish to submit samples of draughtsmanship combined with craftsmanship.

The fewer entrants and the fewer firms taking part in the Competition this year is somewhat disturbing and we hope that more firms will encourage their young apprentices to take part in this Competition and to help to foster an interest in craftsmanship. In spite of the increase in mass production work, there is still scope and indeed necessity for the work of the craftsman in many laboratories.

Prize List

Silvanus P. Thompson Prize (for draughtsmanship and craftsmanship combined)

First Prize: J. S. PALMER (Marconi's Wireless Telegraph Co. Ltd.). Reset motor assembly.

Scientific instruments and components (Junior grade)

First Prize: V. S. MARCHAM (Cambridge Instrument Co. Ltd.). Reflecting electrostatic voltmeter.

Second Prize: R. CROUCHER (Mullard Research Laboratories). Vernier measuring microscope.

Honourable Mention: M. E. ADAMS (National Physical Laboratory). Cantilever lubricator stand.

Scientific instruments and components (Senior grade)

First Prize: J. S. PALMER (Marconi's Wireless Telegraph Co. Ltd.). Reset motor assembly.

Second Prize: P. SHRIVES (Hilger and Watts Ltd.). Measuring microscope workstage unit.

Honourable Mention: M. COLLINS (Hilger and Watts Ltd.). Uvispek lamphouse.

Optical components and systems

First Prize: J. W. L. TAYLOR (Hilger and Watts Ltd.). Pyramid prism.

Second Prize: T. C. DINES (Hilger and Watts Ltd.). Echelon for high resolution spectroscopy.

Third Prize: R. J. MATTES (Hilger and Watts Ltd.). Stopped Rayleigh cell.
Honourable Mention: G. F. HARRIS (Hilger and Watts Ltd.). Linear coded scale.

Blown-glass ware (Junior grade)

First Prize: K. G. WORNHAM (Mullard Research Laboratories). Nine ball condenser.
Second Prize: P. HATCH (Mullard Southampton Works). Reflux condenser.
Third Prize: R. F. WEISS (Associated Electrical Industries Ltd.). Four ball condenser.
Honourable Mention: R. W. CROOK (The Research Laboratories of the G.E.C.). Mercury diffusion pump.

Blown-glass ware (Senior grade)

First Prize: W. MONEY (The Thermal Syndicate Ltd.). Mercury condensation pump.
Second Prize: A. HOPKINS (The Thermal Syndicate Ltd.). Two-stage mercury condensation pump.
Third Prize: M. NASH (The Thermal Syndicate Ltd.). Silica mercury fore pump.
Honourable Mention: K. ROBSON (The Thermal Syndicate Ltd.). Silica mercury condensation pump.

Instructional items. Sections of instruments

Special Prize: M. J. HAYNES (L. Oertling Ltd.). Reproduction 16th-century assayer's balance.
First Prize: R. FRADD (Standard Telephones and Cables). Watchmaker's lathe.
Second Prize: R. FRY (Standard Telephones and Cables). Pneumatic press.
Honourable Mention: J. GOODLAND (Standard Telephones and Cables). Watchmaker's turret lathe.

Microwave components (Senior grade)

First Prize: J. CARRIER (Elliott Bros. (London) Ltd.). Rotary stand wave indicator.
Second Prize: A. E. PEMBROKE (Mullard Research Laboratories). Impedance for 3 cm waveguide.

Electronic circuitry (Junior grade)

First Prize: P. J. PERRY (Royal Radar Establishment). Simple oscilloscope.
Second Prize: J. CROSS (Marconi's Wireless Telegraph Co. Ltd.). Blanking and synchronizing mixer.
Third Prize: J. G. WRAY (National Physical Laboratory). Transistor audio oscillator.

Electronic circuitry (Senior grade)

First Prize: J. L. DE'ATH (Marconi's Wireless Telegraph Co. Ltd.). Translator.
Second Prize: W. G. PAYNE (Hilger and Watts Ltd.). Preamplifier.
Third Prize: S. S. MARTIN (Hilger and Watts Ltd.). Signal generator.

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Notes and comments

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Technique for measuring the elastic properties of bitumens, tars and soils under dynamic loading

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Abstract

A technique is described for the measurement of the components of the complex (dynamic) Young's modulus (E^*) and the complex rigidity modulus (G^*) of bitumens, tars and soils under sinusoidal loading. The equipment is capable of measuring the complex Young's modulus up to about $|E^*| = 5 \times 10^{10}$ dyn/cm² (10^6 lb/in²) and the complex rigidity modulus up to

$$|G^*| = 2 \times 10^{10} \text{ dyn/cm}^2 \text{ (} 3 \times 10^5 \text{ lb/in}^2 \text{)}$$

over the frequency range 5 to 500 c/s and at temperatures between -20 and $+30^\circ \text{C}$.

To measure the complex Young's modulus, an axially sinusoidally varying force is applied to a cylindrical specimen by a moving-coil vibrator. Piezoelectric gauges are used to convert the force applied to the specimen, and the displacement of its driven end, into voltages, which are measured on a phase-sensitive voltmeter. The complex modulus is derived from a comparison of these voltages with those obtained using a steel calibration spring. For the measurement of the complex rigidity modulus, the material is sheared in the annulus between two cylinders, the inner being driven by the vibrator. The same two gauges now serve to measure the force applied to the inner cylinder, its displacement and their relative phase.

Introduction

AN important aspect of the road performance of tars, bitumens and soils is their behaviour under the transient stresses imposed by traffic; this can conveniently be studied by measuring the (complex) stress/strain ratio under sinusoidal loading. Within the region in which the stress/strain relation is linear, their behaviour can be described by the theory of linear viscoelastic materials discussed by, among others, Leaderman (1943) and Gross (1953). By analogy with ordinary elastic theory, three complex moduli can be defined; a complex Young's modulus $E^* = E' + iE''$; a complex shear modulus $G^* = G' + iG''$; and a complex bulk modulus $K^* = K' + iK''$. These are related by the equation

$$\frac{1}{E^*} = \frac{1}{3G^*} + \frac{1}{9K^*} \quad (1)$$

In many cases $|K^*| \gg |G^*|$, so that $E^* = 3G^*$. The behaviour of tars, bitumens and soils under any stress function can be determined if E^* or G^* (or, more conveniently in some cases, their reciprocal, the compliance J^*) are known over the important frequency range.

Measurement of the complex modulus of viscoelastic materials has been increasingly used in recent years, especially for polymers (Stuart 1956).

Bituminous materials have been investigated by van der Poel (1954), who measured the resonant frequency of specimens of various sizes to determine mainly E' , and did not measure E'' separately. However, resonant techniques are best suited to relatively high frequencies and have the further disadvantage that results are obtained only at specific resonant frequencies determined by the dimensions of the specimen.

The present instrument has been designed to measure the two components of the complex Young's modulus E^* of bitumens, tars and soils, up to a value of $|E^*|$ of about 5×10^{10} dyn/cm² (10^6 lb/in²), and of the complex shear modulus G^* up to $|G^*|$ of about 10^{10} dyn/cm², over the frequency range 5 to 500 c/s, and at temperatures between -20 and $+30^\circ \text{C}$. Tensile stresses of up to 7×10^5 dyn/cm² (10 lb/in²) are used in the determination of E^* , and shear stresses of up to 4×10^5 dyn/cm² (5 lb/in²) for determining G^* .

General description of the equipment

A block schematic diagram of the apparatus is shown in Fig. 1, and a circuit diagram of those units not commercially available is shown in Fig. 2. A variable-frequency oscillator drives a moving-coil vibrator via a 50 w power amplifier, the force developed being applied to the specimen. To measure the complex Young's modulus E^* , the specimen is in the form of a cylinder (normally 3 in. long and 1 in. in diameter) which is cemented to the upper platen attached to the moving coil. The other end of the specimen is cemented to the lower platen, which contains a piezoelectric ceramic element to measure the force. Adjustment of the height of the lower platen is provided by a screw working in the rigid base of the vibrator assembly. A light metal rod, attached to the upper platen, passes through the centre pole of the magnet and drives a piezoelectric gauge to measure the displacement of the upper platen. This gauge consists of a barium titanate bimorph cemented at the four corners of its upper face to four screws carried on the body of the gauge. At the centre of the lower face a light helical spring is fixed, the other end of which is attached to the rod from the upper platen. As this moves, the spring is compressed, thus flexing the bimorph.

The rod driving the displacement gauge also engages with an electromagnetically operated latch, which serves to support the weight of the upper platen when measurements are not being made. During actual testing of bitumens and tars, the weight of the platen is balanced by passing a direct current through the coil, in addition to the alternating drive current; this is necessary because of the creep that would otherwise occur. For testing soils, however, most of which are incapable of supporting much tension, the compressive force due to the platen is increased by reversing and increasing the direct current, so that the net force on the specimen

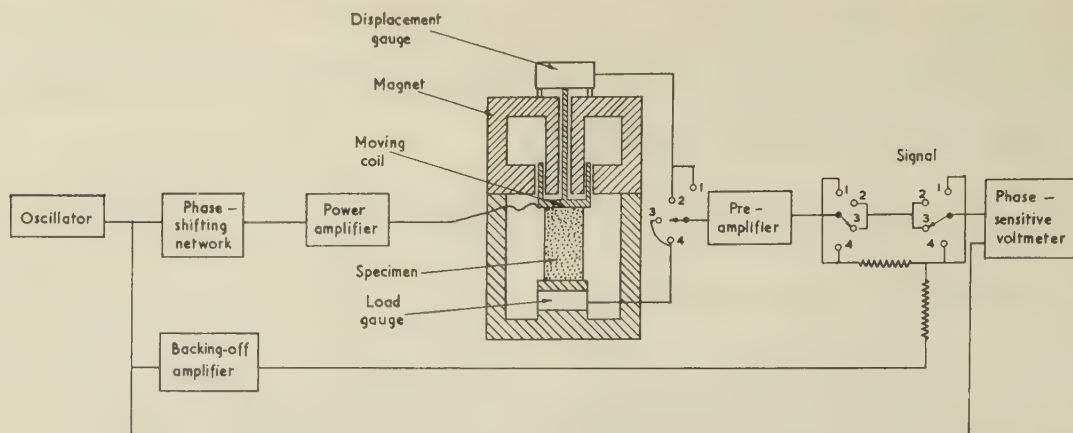


Fig. 1. Schematic diagram of apparatus for measuring the elastic properties of bitumens, tars and soils.

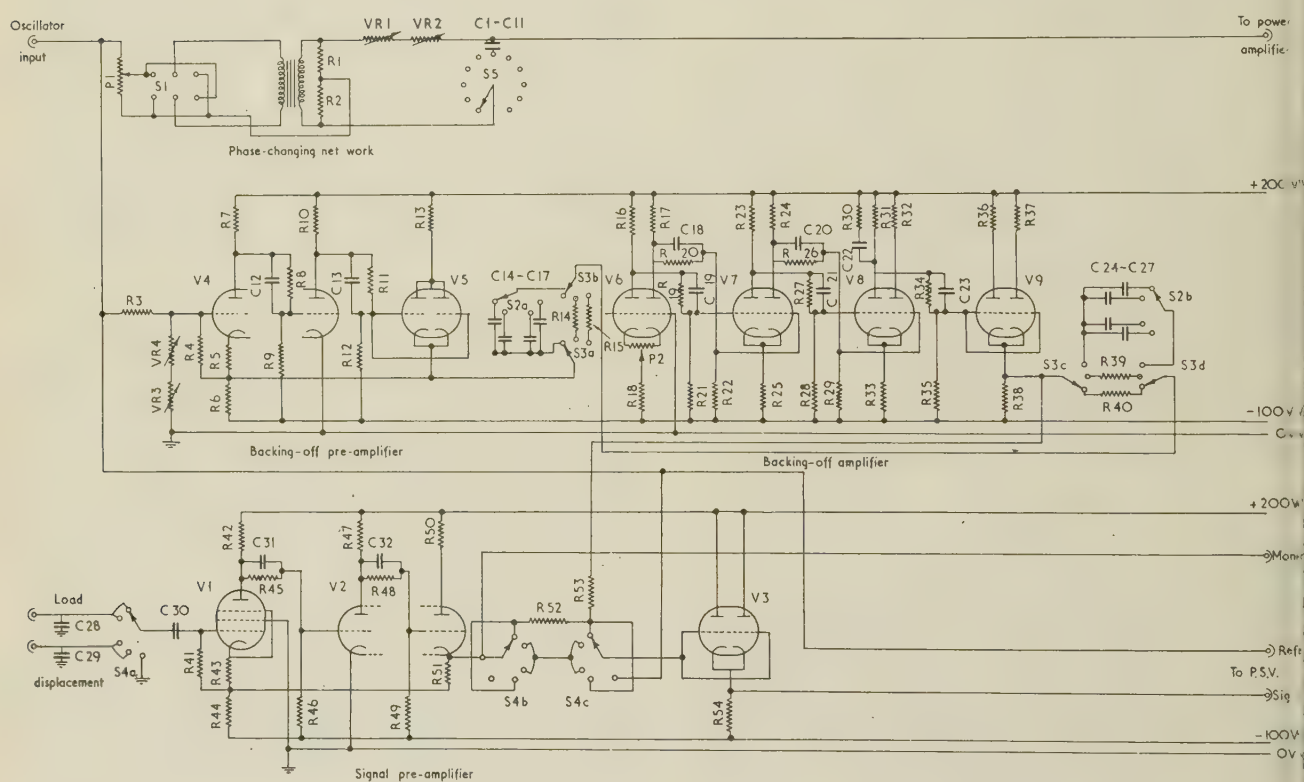


Fig. 2. Circuit diagram of control gear.

$R_1, R_2 = 100 \text{ k}\Omega$
 $R_3 = 10 \text{ k}\Omega$
 $R_4 = 2.2 \text{ M}\Omega$
 $R_5 = 1.2 \text{ k}\Omega$
 $R_6 = 12 \text{ k}\Omega$
 $R_7 = 100 \text{ k}\Omega$
 $R_8, R_9 = 150 \text{ k}\Omega$
 $R_{10} = 100 \text{ k}\Omega$
 $R_{11}, R_{12} = 150 \text{ k}\Omega$
 $R_{13} = 100 \Omega$
 $R_{14}, R_{15} = 33 \text{ k}\Omega$
 $R_{16}, R_{17} = 39 \text{ k}\Omega$
 $R_{18} = 27 \text{ k}\Omega$
 $R_{19}, R_{20} = 150 \text{ k}\Omega$
 $R_{21} = 100 \text{ k}\Omega$
 $R_{22} = 150 \text{ k}\Omega$
 $R_{23}, R_{24} = 39 \text{ k}\Omega$
 $R_{25} = 27 \text{ k}\Omega$
 $R_{26}, R_{29} = 150 \text{ k}\Omega$
 $R_{30} = 1 \text{ k}\Omega$
 $R_{31} = 68 \text{ k}\Omega$
 $R_{32} = 100 \Omega$

$R_{33} = 15 \text{ k}\Omega$
 $R_{34}, R_{35} = 150 \text{ k}\Omega$
 $R_{36}, R_{37} = 100 \Omega$
 $R_{38} = 12 \text{ k}\Omega$
 $R_{39}, R_{40} = 33 \text{ k}\Omega$
 $R_{41} = 3.3 \text{ M}\Omega$
 $R_{42} = 82 \text{ k}\Omega$
 $R_{43} = 1.2 \text{ k}\Omega$
 $R_{44} = 470 \Omega$
 $R_{45}, R_{46} = 1 \text{ M}\Omega$
 $R_{47} = 33 \text{ k}\Omega$
 $R_{48}, R_{49} = 1 \text{ M}\Omega$
 $R_{50} = 100 \Omega$
 $R_{51} = 12 \text{ k}\Omega$
 $R_{52}, R_{53} = 50 \text{ k}\Omega$
 $R_{54} = 12 \text{ k}\Omega$
 $C_1 = 1000 \text{ pF}$
 $C_2 = 2000 \text{ pF}$
 $C_3 = 0.004 \mu\text{F}$
 $C_4 = 0.008 \mu\text{F}$
 $C_5 = 0.015 \mu\text{F}$

$C_6 = 0.033 \mu\text{F}$
 $C_7 = 0.068 \mu\text{F}$
 $C_8 = 0.12 \mu\text{F}$
 $C_9 = 0.25 \mu\text{F}$
 $C_{10} = 0.5 \mu\text{F}$
 $C_{11} = 1.0 \mu\text{F}$
 $C_{12}, C_{13} = 100 \text{ pF}$
 $C_{14} = 0.01 \mu\text{F}$
 $C_{15} = 0.03 \mu\text{F}$
 $C_{16} = 0.1 \mu\text{F}$
 $C_{17} = 0.3 \mu\text{F}$
 $C_{18} - C_{21} = 100 \text{ pF}$
 $C_{22} = 300 \text{ pF}$
 $C_{23} = 50 \text{ pF}$
 $C_{24} = 1.0 \mu\text{F}$
 $C_{25} = 0.3 \mu\text{F}$
 $C_{26} = 0.1 \mu\text{F}$
 $C_{27} = 0.03 \mu\text{F}$
 $C_{28} \dots C_{32} = \text{depend on gauges}$
 $C_{30} = 1.0 \mu\text{F}$
 $C_{31}, C_{32} = 50 \text{ pF}$

$VR_1 = 10 \text{ k}\Omega$
 $VR_2 = 100 \text{ k}\Omega$
 $VR_3 = 100 \Omega$
 $VR_4 = 1 \text{ k}\Omega$

$P_1 = 50 \text{ k}\Omega$
 $P_2 = 1 \text{ k}\Omega$
 $S_1 = \text{phase reversing switch.}$
 $S_2 = 2\text{-pole, 4-way. Adjust for frequency.}$
 $S_3 = 4\text{-pole, 3-way. } 90^\circ, 180^\circ, 270^\circ$
 $S_4 = 3\text{-pole, 5-way. Load, strain, back-off load, back-off strain, set up.}$
 $S_5 = 11\text{-way, 1-pole. Set phase coarse.}$

$V_1 = \text{EF86}$
 $V_2, V_3 = \text{ECC81}$
 $V_4 = \text{ECC83}$
 $V_5 - V_9 = \text{ECC81}$

always compressive; this necessarily limits the peak stress that can be imposed on the soil.

To measure the complex shear modulus G^* of fluid materials, such as soft bitumens, that will not retain a cylindrical shape, the material is sheared in the annulus between an outer cylindrical container (see Fig. 3) and an inner cylinder to which the force is applied. The same two gauges now serve to measure the force transmitted to the outer cylinder and the displacement of the inner driven cylinder. In this form, the apparatus is similar to that described by Markovitz (1952) and Markovitz *et al.* (1952). For either type of test, the whole vibrator assembly is con-

giving in conjunction with the capacitors shunting the gauges a time constant of about 5 seconds.

Specimens

The cylindrical specimens, 3 in. long by 1 in. in diameter, are made in moulds by a casting technique for bituminous materials and by compaction for soils. With bituminous specimens, steel end-caps are attached by warming them and placing them in contact with the ends of the specimen in a jig. These caps are then cemented to the platens with Araldite D resin. Soil specimens are cemented in position directly, without end-caps, using plaster of Paris. They are covered with a thin layer of soft wax to reduce moisture losses during test.

For the shear tests, three cups are used to cover the range. They are all of the form shown in Fig. 3, and they consist of an inner cylinder and an outer cylindrical container screwed to a base-plate. The bottom of the annulus is closed by a thin (0.003 in.) plastic disk, which supports the material contained in the cup without contributing significantly to its rigidity. Since the cup and the material under test have normally to be heated to temperatures of up to 130° C for filling with bituminous materials, polytetrafluoroethylene (p.t.f.e.) was used for this purpose. The instruments have the dimensions given in the table; they are filled by heating the liquid and cups to a suitable temperature and pouring sufficient material into the outer container. The inner cylinder is then inserted, squeezing the liquid up into the annulus. The inner cylinder can then be locked in the coaxial position, by means of three lugs attached to the outer cylinder, while the liquid cools and until the cup is set in position in the vibrator assembly. The lugs are then removed and the inner core is vibrated in the axial direction. The amplitude of the movement of this core is measured, together with the force transmitted via the specimen to the outer wall of the holder.

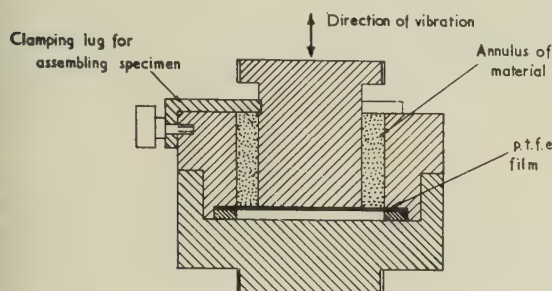


Fig. 3. Cup for determining the complex shear modulus G^* .

ned in a temperature-controlled cabinet, the temperature which can be controlled over the range -20 to $+30^\circ\text{C}$. The load and displacement gauges were calibrated jointly using as a specimen a steel helical spring, the rate of which had been determined statically. From the known spring rate and the observed ratio between the outputs of the load and displacement gauges, a factor was obtained to convert from the observed voltage ratio for other specimens to their stiffness or compliance.

The voltages developed by the two gauges are passed in turn through a pre-amplifier having a gain of about 50, and thence to a phase-sensitive voltmeter. This instrument, type VP250, made by Solartron Ltd., consists basically of two thermocouple wattmeters. One circuit of each meter is fed from a reference signal of the same frequency that to be measured, in one case directly from an amplifier and in the other from the same amplifier via a 90° phase-shifting network. The signal to be measured is passed via an amplifier, identical to that used for the reference signal, to the second circuit of both meters. The first thus displays the component of the signal that is in phase with the reference signal, and the second meter displays the component that is in quadrature with the reference, i.e. the two meters display respectively the real and imaginary components of the signal vector with respect to the reference vector.

The phase-sensitive voltmeter cannot normally be used below 20 c/s but, by adding an extra capacitor to the phase-shifting network feeding the quadrature meter, it can be used down to 5 c/s. This extension of range is valid in the present case because the instrument is intended to give only the ratio of two voltages fed successively to the same instrument, and absolute accuracy is not necessary. For the same reason, the gain and phase characteristics of the signal pre-amplifier are not important; it is only necessary that its input impedance shall be high enough to enable the piezoelectric gauges to work down to the lowest frequencies at which measurements are made. Its actual input impedance is about $50\text{ M}\Omega$,

Dimensions of concentric cylinder apparatus

Cup no.	Inner cylinder radius (r_2) (in.)	Outer cylinder radius (r_1) (in.)	Depth (l) (in.)	$\ln \frac{(r_1/r_2)}{2\pi l}$
1	0.331	0.375	1.00	2×10^{-2}
2	0.547	0.750	1.00	5×10^{-2}
3	0.276	0.750	1.00	1/6

Measuring procedure

The procedure adopted for measuring compliance J^* will be described; that for measuring modulus E^* is basically similar.

The output from the oscillator is fed to the reference channel of the p.s.v., and the load signal is fed via the pre-amplifier (V_1 , V_{2a} , V_{2b} and V_3 in Fig. 2) to the signal channel. The drive to the power amplifier passes through a phase-shifting network, by means of which its phase can be adjusted so that the load-signal is in phase with the reference signal, i.e. the quadrature meter reading is zero. The reading on the reference meter then gives the amplitude of the load signal. The displacement signal is next fed via the pre-amplifier to the signal channel of the phase-sensitive voltmeter, the two meters of which now display the real and imaginary components of the displacement. Dividing these two component signals by the load signal, and multiplying by the calibration constant derived from the spring, yields the two components of the compliance of the specimen (subject to small corrections described later).

It often happens (e.g. with bitumen tested at high frequencies or low temperatures) that the imaginary component of the displacement is small compared with the real component and is difficult to measure as accurately. Provision is therefore made to add to the displacement signal a 'backing-off' voltage exactly in anti-phase with the reference signal. By adjusting the amplitude of this backing-off voltage, the real component of the displacement signal can be cancelled, permitting the sensitivity of the phase-sensitive voltmeter to be increased as necessary to measure the imaginary component. This facility also increases the accuracy of the initial setting of the phase of the load signal.

On the other hand, the real component can become much less than the imaginary component, and the backing-off voltage must then be set in quadrature with the reference voltage to raise the sensitivity as before. It must, in fact, be at 90° if the compliance is being measured, and at 270° if the modulus is being measured. Voltages accurately at 90° , 180° and 270° to the reference voltage are therefore needed, and are derived from the amplifier formed by V_6 - V_9 in Fig. 2 (shown schematically in Fig. 4) which can be

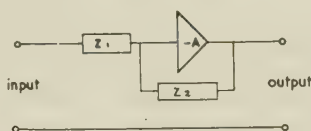


Fig. 4. Schematic diagram of backing-off amplifier.

switched to reverse the phase of the input signal, to integrate it or to differentiate it.

The feedback to the input of this backing-off amplifier reduces its input impedance so that, to avoid the risk of phase changes occurring because of the consequent capacitive loading on the amplitude control, it is fed from an amplifier (V_{4a} , V_{4b} and V_5 in Fig. 2), the output impedance of which has been reduced by negative feedback to about 0.5Ω .

The output from the backing-off amplifier is fed together with the displacement signal to an adding network consisting of two resistors, R_{52} and R_{53} in Fig. 2. The voltage appearing at their junction is fed to the phase-sensitive voltmeter; since this voltage is the average of the backing-off and signal voltages, the residual-voltage reading on the phase-sensitive voltmeter must be doubled to give the actual value of the signal component being measured.

Acknowledgments

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Appendix

Theoretical treatment

Cylindrical specimens. Neglecting inertia effects, i.e. at sufficiently low frequencies, the relation between the observed compliance C^* (cm/dyn) and the complex compliance of the material J^* (cm²/dyn) is, of course, merely $J^* = AC^*/L$, where L equals the specimen length and A equals the specimen cross-sectional area. At higher frequencies, when the specimen becomes a significant part of the wavelength of the vibrations in it, inertia effects will become important.

The equation for sinusoidal oscillations in the cylinder is

$$\frac{\partial^2 u}{\partial x^2} = J^* \rho \frac{\partial^2 u}{\partial t^2} \quad (2)$$

where u = displacement at x and ρ = density, i.e. the usual wave equation except that J^* is now complex. Its solution, subject to the boundary conditions that $u = u_0 \exp(i\omega t)$ at $x = L$, and $u = 0$, $x = 0$, is:

$$u = \frac{u_0 \sin x \sqrt{(\omega^2 \rho J^*)}}{\sin L \sqrt{(\omega^2 \rho J^*)}} \exp(i\omega t). \quad (3)$$

Measurements are actually made of the ratio C^* between the displacement at the top of the cylinder and the force on the bottom platen.

The stress at $x = 0$ is:

$$\frac{1}{J^*} \left(\frac{\partial u}{\partial x} \right)_{x=0} = \frac{u_0 \sqrt{(\omega^2 \rho J^*)}}{J^* \sin L \sqrt{(\omega^2 \rho J^*)}} \exp(i\omega t) \quad (4)$$

thus

$$C^* = \frac{J^* \sin L \sqrt{(\omega^2 \rho J^*)}}{A \sqrt{(\omega^2 \rho J^*)}}.$$

Expanding as a series, it is found that

$$C^* = \frac{LJ^*}{A} \left(1 - \frac{\omega^2 \rho L^2 J^*}{6} + \frac{\omega^4 L^4 \rho^2 J^{*2}}{120} \dots \right) \quad (5)$$

which can be inverted to give

$$J^* = J_0^* \left(1 + \frac{\omega^2 L^2 \rho J_0^*}{6} + \frac{17}{360} \omega^4 L^4 \rho^2 J_0^{*2} + \dots \right) \quad (6)$$

where

$$J_0^* = (A/L)C^*.$$

With bitumens and tars, which have a density of about 1 g/cm^3 , it is unlikely that terms of higher order than the second will be necessary up to the limit of 500 c/s. For materials of higher density, such as soils, however, higher terms may become significant.

Coaxial cylinders. The width of the annulus is taken to be sufficiently small compared with its length to ensure that the deformation of the material is essentially a function only of the radius and the time, i.e. that successive annuli are simply sheared against each other. In this case, the one-dimensional wave equation again applies, this time in polar coordinates:

$$\rho J_s^* \frac{\partial^2 u}{\partial r^2} = \frac{\partial^2 u}{\partial r^2} + \frac{1}{r} \frac{\partial u}{\partial r} \quad (7)$$

in which J_s^* is the shear compliance ($1/G^*$), and ρ is the

nsity. The solution, subject to the boundary conditions $u = 0$, $r = r_1$, and $u = u_0 \exp(i\omega t)$, $r = r_2$, is

$$u = u_0 \exp(i\omega t) \frac{Y_0(ar_1)J_0(ar) - J_0(ar_1)Y_0(ar)}{J_0(ar_1)Y_0(ar_2) - Y_0(ar_1)J_0(ar_2)} \quad (8)$$

where $J_0(x)$, $Y_0(x)$ are Bessel functions, and $a = \omega\sqrt{(J_s^*\rho)}$. Again, interest lies with the ratio C^* between the displacement of the inner cylinder and the force on the outer.

$$\text{Stress at outer cylinder wall} = \frac{1}{J_s^*} \left(\frac{\partial u}{\partial r} \right)_{r=r_1}$$

$$\text{force on outer cylinder} = \frac{2\pi r_1 l}{J_s^*} \left(\frac{\partial u}{\partial r} \right)_{r=r_1} = \frac{2\pi r_1 l}{J_s^*} u_0 \exp(i\omega t) a \cdot \frac{Y_0(ar_1)J_0'(ar_1) - J_0(ar_1)Y_0'(ar_1)}{J_0(ar_1)Y_0(ar_2) - Y_0(ar_1)J_0(ar_2)} \quad (9)$$

and since $Y_0(x)J_0'(x) - J_0(x)Y_0'(x) = -2/\pi x$ the force on the outer wall is

$$-4lu_0 \exp(i\omega t) \frac{J_s^* \{J_0(ar_1)Y_0(ar_2) - Y_0(ar_1)J_0(ar_2)\}}{J_s^* \{J_0(ar_1)Y_0(ar_2) - Y_0(ar_1)J_0(ar_2)\}} \quad (10)$$

$$\text{hence } C^* = \frac{-J_s^* \{J_0(ar_1)Y_0(ar_2) - Y_0(ar_1)J_0(ar_2)\}}{4l} \quad (11)$$

Using the series for $J_0(x)$ and $Y_0(x)$

$$J_0(x) = 1 - \frac{x^2}{4} + \frac{x^4}{64} \dots \quad (12)$$

and

$$Y_0(x) = \frac{2}{\pi} \left\{ J_0(x) \left(\ln \frac{x}{2} + \gamma \right) + \frac{x^2}{4} - \frac{3x^4}{128} \dots \right\}, \quad \gamma = 0.5772 \dots \quad (13)$$

It is found that

$$C^* = \frac{J_s^* \ln(r_1/r_2)}{2\pi l} (1 - K_1 \omega^2 \rho J_s^* + L_1 \omega^4 \rho^2 J_s^{*2} + \dots) \quad (14)$$

$$\text{where } K_1 = \frac{1}{4} [r_1^2 + r_2^2 - \{(r_1^2 - r_2^2)/\ln(r_1/r_2)\}]$$

$$\text{and } L_1 = \frac{r_1^2 r_2^2}{16} + \frac{r_1^4 + r_2^4}{64} - \frac{3(r_1^4 - r_2^4)}{128 \ln(r_1/r_2)}$$

This can be inverted to give finally

$$J_s^* = \frac{2\pi l}{\ln(r_1/r_2)} C^* (1 + KC^* + LC^{*2} + \dots) \quad (15)$$

$$\text{where } K = -\frac{\pi \omega^2 l \rho}{2 \ln(r_1/r_2)} \left(r_1^2 + r_2^2 - \frac{r_1^2 - r_2^2}{\ln(r_1/r_2)} \right)$$

$$L = \frac{4\pi^2 l^2 \omega^4 \rho^2}{\{\ln(r_1/r_2)\}^2} \left(\frac{r_1^4 + r_2^4}{8} \left[\frac{7}{8} + \frac{1}{\{\ln(r_1/r_2)\}^2} \right] + \frac{r_1^2 r_2^2}{16} \left[3 - \frac{4}{\{\ln(r_1/r_2)\}^2} \right] - \{29(r_1^4 - r_2^4)/128 \ln(r_1/r_2)\} \right)$$

The actual design of the cups is a compromise between various conflicting requirements. First, the annulus must be relatively narrow compared with its length. Secondly, their dimensions should be such as to reduce the importance of the higher terms in this series. Finally, the inner and outer cylinders themselves must be extremely rigid compared with the effective stiffness of the material under test. Three cups have been designed, the dimensions of which, together with the value of the 'zero frequency' calibration constant $\ln(r_1/r_2)/2\pi l$, are given in the Table. The first cup covers the range $|J_s^*| = 3 \times 10^{-8} \text{ cm}^2/\text{dyn}$ ($2 \times 10^{-3} \text{ in}^2/\text{lb}$) to $5 \times 10^{-11} \text{ cm}^2/\text{dyn}$ ($3 \times 10^{-6} \text{ in}^2/\text{lb}$), and the second the range $|J_s^*| = 5 \times 10^{-7} \text{ cm}^2/\text{dyn}$ ($3 \times 10^{-2} \text{ in}^2/\text{lb}$) to

$$|J_s^*| = 6 \times 10^{-9} \text{ cm}^2/\text{dyn} (2 \times 10^{-4} \text{ in}^2/\text{lb}).$$

For both these cups, the second and higher terms are negligible (less than 1%) within the frequency range 5 to 500 c/s. The last cup has been designed to measure higher values of G^* , and so to permit a greater overlap with the results from the cylindrical specimens; in this case, the first correction term has to be taken into account over a large part of the range, though the second is usually negligible.

Simple amplifier and pulse-height analyser for an x-ray scintillation counter

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Abstract

A simple circuit, using only four valves, has been developed to serve as amplifier and pulse-height analyser for an x-ray scintillation counter. Results obtained suggest that large noise pulses in the photomultiplier may be caused by repeated optical feedback.

1. The circuit and its performance

SCINTILLATION counters for x-ray diffractometry have hitherto been used with standard linear amplifiers and pulse-height analysers (e.g. Parrish and Kohler 1956). Since the output signal from the counter requires little amplification, and since the x-ray energy resolution is limited by the small number of electrons emitted from the photomultiplier cathode (Parrish and Kohler 1956), it was felt that simpler electronic equipment would be adequate. The results of an attempt to develop the simplest possible circuit for this purpose are described in this paper.

Circuit action. The scintillation counter consisted of a Harshaw thallium-activated sodium iodide crystal mounted on an E.M.I. type 9524B photomultiplier; Cu K α x-radiation was used in the experiments.

The circuit used with the counter is shown in Fig. 1. The anode and final dynode of the photomultiplier are connected to the grids of the double triode valve V_2 , so that the waveform of the net current drawn from the combined anodes of this valve is similar in shape to the algebraic sum of the negative voltage pulse at the photomultiplier anode and the positive pulse at the final dynode. The anode and final dynode circuits have time constants of $0.4 \mu\text{s}$ and $0.25 \mu\text{s}$ respectively. These values were chosen to reduce the resolution time of the system as much as possible, without attenuating the pulse heights unduly (sodium iodide (thallium-activated) crystals have a decay time constant of approximately $0.2 \mu\text{s}$ (Parrish and Kohler 1956)). The ratio between the time constants was chosen to ensure that the dynode pulse cannot linger after the anode pulse has died away, which might produce a spurious count. The component values in these circuits were also chosen so that the peak height of the dynode voltage pulse is twice that of the anode pulse, when both are sufficiently small. The dynode pulse, however, is prevented from exceeding a certain height by the action of the germanium diode D_1 . As the magnitude of the photomultiplier input signal is increased, the net charge drawn from the anodes of V_2 therefore rises to a maximum (corresponding to the onset of conduction in D_1), and then falls, becoming negative for very large input signals. The 2 : 1 ratio of the dynode and anode pulse amplitudes

was intended to make the slope of the fall from the maximum approximately equal to the slope of the rise to the maximum. Owing to the integrating effect of the capacitance of the cable linking the photomultiplier to the remainder of the circuit, the amplitudes of the negative voltage pulses at the anodes of V_2 are approximately proportional to the net charges drawn from the anodes. Resistor R_{17} is chosen to give an integrating time constant of $0.25 \mu\text{s}$; again this is a compromise between resolution time and pulse height. Thus, as the magnitude of the photomultiplier input signal is increased, the maximum amplitude attained by these voltage pulses also increases and then decreases; if the pulses are then inverted in sign and fed into a simple pulse-height discriminator, every photomultiplier input signal lying in a magnitude between two limiting values will give rise to an output signal from the discriminator. Pulse-height analysis can therefore be achieved; the upper and lower limits are set indirectly by adjustment of the photomultiplier gain and the discriminator setting. Fig. 2 shows the idealized waveforms in the circuit. The calculations on which the curves are based, which are available elsewhere (Trott 1959), also predict that the circuit should exhibit good noise-rejection properties.

The discriminator is made up of V_{3A} (sign-inverting amplifier), V_{3B} (cathode follower), V_4 and V_{5A} (Schmitt trigger circuit) (Farley 1956), and V_{5B} (output cathode follower). Variation of R_{26} changes the steady grid potential of V_{3B} , and hence the steady potential difference across its cathode resistor R_{23} ; the bias on the trigger circuit is thus made variable. Long-term variation in the gain of the amplifier can be corrected by adjustment of R_{21} . The value of R_{29} was selected to give a backlash of 1.0 v in the trigger circuit. The combination of R_{24} and D_2 in the grid circuit of V_{3B} minimizes drifting of the steady grid potential due to positive signals, without allowing the occasional negative signals to cause appreciable reverse drifting. Diode D_3 prevents drifting of the steady grid potential of V_{5B} , while R_{34} reduces the grid current in this valve.

Setting-up the circuit. The counting system must necessarily be set up indirectly by adjustment of the photomultiplier e.h.t. voltage and the discriminator bias voltage. Ideally the counter should receive monochromatic radiation during this operation. For the present work the (111) line of an aluminium powder specimen was used, the beam passing through a β -filter. The angular width of the receiving slit was 0.3° , and it was thought that the effect of the non-characteristic component (approximately 1%) would be negligible.

The e.h.t. voltage is first set so that the pulse height produced at the final dynode by the characteristic radiation (with D_1 disconnected) is approximately equal to the value at which D_1 begins to conduct (0.6 v in the present case). The

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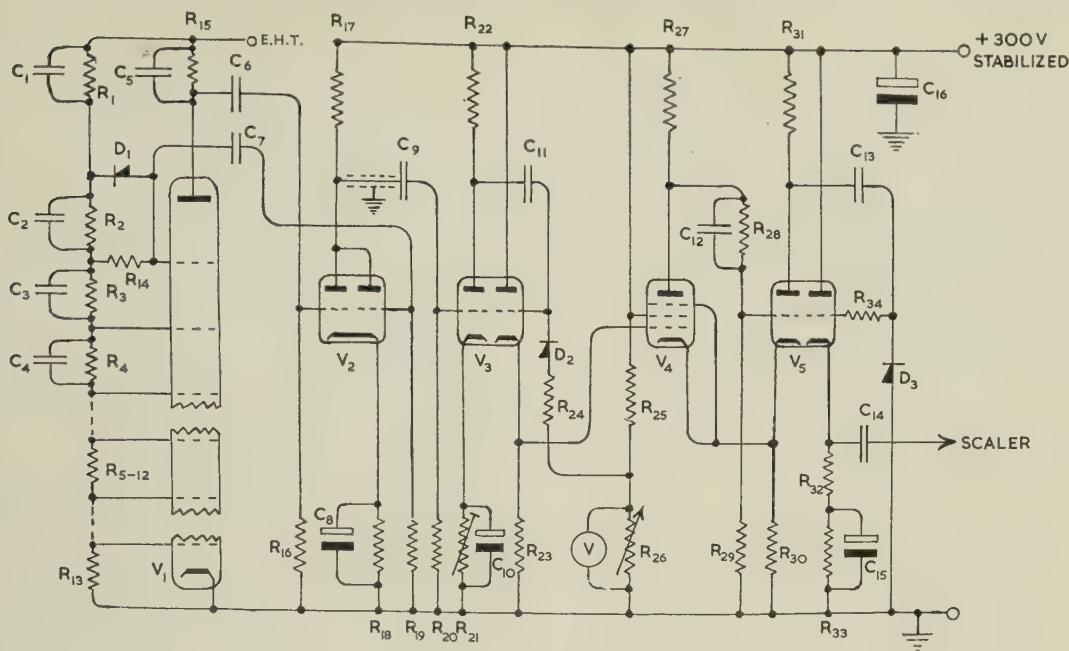


Fig. 1. Scintillation head and pulse-height analyser.

$R_1 = 2 \text{ M}\Omega$
 $R_2 = 7.5 \text{ k}\Omega$
 $R_3, R_4 = 2 \text{ M}\Omega$
 $R_5 - R_{13} = 1 \text{ M}\Omega$
 $R_{14} = 10 \text{ k}\Omega$
 $R_{15} = 7 \text{ k}\Omega$
 $R_{16} = 1 \text{ M}\Omega$
 $R_{17} = 3.5 \text{ k}\Omega$
 $R_{18} = 250 \Omega$
 $R_{19} = 1 \text{ M}\Omega$
 $R_{20} = 600 \text{ k}\Omega$
 $R_{21} = 5 \text{ k}\Omega$ (amplifier gain) (set at $2 \text{ k}\Omega$)

$R_{22}, R_{23} = 10 \text{ k}\Omega$
 $R_{24} = 100 \text{ k}\Omega$
 $R_{25} = 20 \text{ k}\Omega$
 $R_{26} = 2.5 \text{ k}\Omega$ max. (set discriminator)
 $R_{27} = 10 \text{ k}\Omega$
 $R_{28} = 35 \text{ k}\Omega$
 $R_{29} = 6 \text{ k}\Omega$ (selected to give 1.0 v backlash)
 $R_{30} = 4 \text{ k}\Omega$
 $R_{31} = 1 \text{ k}\Omega$
 $R_{32} = 500 \Omega$
 $R_{33} = 6 \text{ k}\Omega$

$R_{34} = 15 \text{ k}\Omega$
 $C_1, C_2 = 0.1 \mu\text{F}$
 $C_3 = 500 \text{ pF}$
 $C_4 = 100 \text{ pF}$
 $C_5 = 30 \text{ pF}$
 $C_6, C_7 = 1200 \text{ pF}$
 $C_8 = 8 \mu\text{F}$
 $C_9 = 200 \text{ pF}$
 $C_{10} = 8 \mu\text{F}$
 $C_{11} = 2000 \text{ pF}$
 $C_{12} = 5 \text{ pF}$

$C_{13} = 100 \text{ pF}$
 $C_{14} = 0.01 \mu\text{F}$
 $C_{15}, C_{16} = 8 \mu\text{F}$

$D_1, D_2, D_3 = \text{GEX } 54$

$V_1 = \text{E.M.I. } 9524\text{B}$ photomultiplier
 $V_2 = \text{ECC85}$
 $V_3 = 12\text{AU7}$
 $V_4 = \text{Z77}$
 $V_5 = \text{ECC85}$

variation of the counting rate with the discriminator bias is then found at constant e.h.t. voltage; the curve is corrected for photomultiplier noise by measuring and subtracting the noise counting rate at each bias value. Next the bias is set to give the required percentage of the maximum counting rate (e.g. 90%, following Parrish and Kohler 1956), and the e.h.t. voltage is adjusted to give the maximum counting rate obtainable at this bias setting. A fresh counting rate/bias

graph is then plotted, and the procedure repeated until no further changes in the e.h.t. voltage and the discriminator bias voltage are required. The whole process takes little time, and routine readjustment is rapid once the approximate settings are known. The percentage of the characteristic radiation to be admitted is chosen to give a compromise between x-ray energy resolution and rejection of photomultiplier noise on the one hand, and x-ray counting

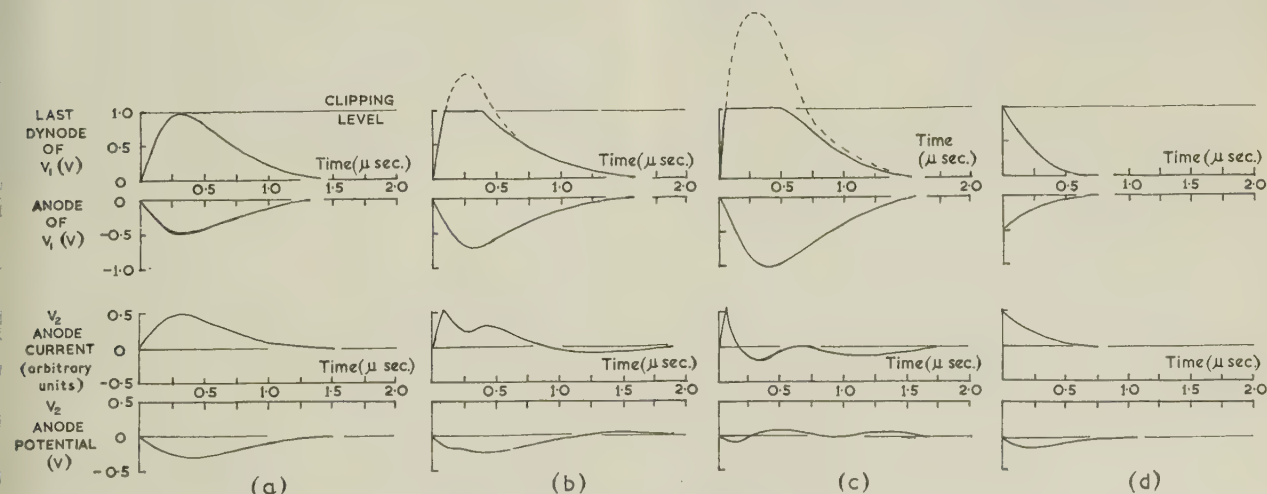


Fig. 2. Idealized waveforms due to:
 (a) largest possible unclipped x-ray pulse;
 (b), (c) x-ray pulses of greater amplitude than (a);
 (d) largest possible noise pulse.

efficiency and sensitivity of the counting rate to changes in the discriminator setting on the other.

Circuit performance. Fig. 3 shows a typical counting rate/bias graph (corrected for photomultiplier noise), obtained when the circuit had been set up. The flattest portion of the curve was taken to represent the maximum possible counting rate for the characteristic radiation; the sharp rise above this rate is ascribed to non-characteristic radiation and photomultiplier noise. With the discriminator set at 10.0 v, the counting rate was 90% of the maximum. A change of 1 v in the discriminator bias produced a 6% change in the counting rate. A change of 5 v in either direction in the e.h.t. voltage, which was 1360 v, reduced the counting rate

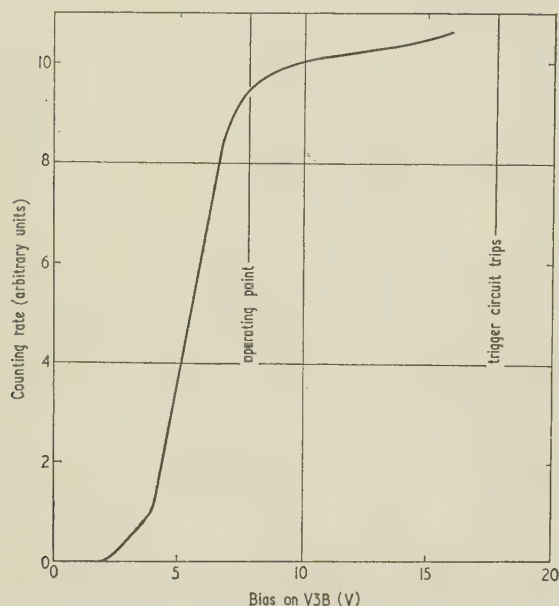


Fig. 3. Graph of counting rate versus bias on V_{3B} at constant x-ray intensity.

by 1%. The noise counting rate was one per minute. Extrapolation of results obtained at lower e.h.t. voltages suggested that, in the absence of the action of D_1 , the characteristic radiation would have produced a (mean) pulse height of approximately 20.0 v at 1.36 kv.

2. The source of photomultiplier noise

Experimental results. Fig. 4 (solid points) shows the pulse-height distributions due to photomultiplier noise found at four e.h.t. values, when a simple discriminator was connected via an orthodox linear amplifier to the anode of the photomultiplier. The anode time constant was 1 μ s. No signal was taken from the final dynode. The curves terminate at a rate of approximately two counts per second because of interference from cosmic radiation. No pulse-height analyser was available, and redesigning the counter arrangement was considered undesirable. The circles on the 1.36 kv section of this figure show the noise pulse-height distribution obtained with the simplified circuit described above at this e.h.t. value. (The values for the pulse heights have been divided by the ratio between the mean x-ray pulse height obtained with the simplified circuit and the mean x-ray pulse height obtained with the orthodox connections at this e.h.t. value.)

Now if large noise pulses are simply noise pulses that have

received excessive amplification, their time spread at the anode end of the photomultiplier should be short, relative to 0.25 μ s. Therefore, with the simplified circuit described above, the largest possible signal at the final dynode should consist of an exponential decay (time constant 0.25 μ s) from the voltage at which D_1 conducts. The accompanying signal at the anode should be approximately half as high initially, and should decay with a time constant of 0.4 μ s. It can be calculated (Trott 1959) that the corresponding signal at the anodes of V_2 should be slightly less than half the height of the largest possible x-ray pulse (Fig. 2(a) and 2(d)). Thus if the discriminator is set at approximately half the maximum x-ray pulse-height, the counting rate due to photomultiplier noise should be zero and the rate should be considerably reduced at discriminator settings approaching this. In practice, this was not found; the two '1360 v' curves of Fig. 4 coincide on a single straight line.

Discussion. The large pulses could not be caused by radioactivity from potassium in the tube window (Pelchowitch 1955, Koechlin *et al.* 1954), since the glass has a low potassium content. It seems probable that they are noise pulses extended in time. If they were each spread over 0.3 μ s (Davison 1952) the final pulse height would be altered very little, but the maximum pulse height at the final dynode (where D_1 operates) would be reduced very considerably. It is necessary to find an explanation for this time spread, and also for the accurately exponential lower portions of the curves of Fig. 4 (which agree with the results of Harrison (1952)).

One possible explanation is that the large noise pulses are multiple pulses caused by repeated optical feedback in the photomultiplier. Such pulses would be spread over an extended period owing to the transit times of the electron showers. Let each electron shower have a probability p of causing a fresh electron to be emitted from the cathode and let noise electrons leave the cathode at a rate of r per second. Then, neglecting statistical variation in p , the rate S at which pulses n or more times the height V_1 of a single shower pulse reach the anode is given by

$$S = rp^{n-1}$$

or

$$\log S = \log r + (n-1) \log p.$$

This distribution would be represented on Fig. 4 by a straight line passing through the point $(V_1, \log r)$; V_1 would be only slightly smaller than the overall mean pulse height V_2 , provided that large pulses were infrequent. If p showed appreciable statistical variation, the distribution would vary from this, but a straight line passing close to the point $(V_2, \log r)$ might still be expected. Now the curves of Fig. 4 become good straight lines at large pulse heights, but if extrapolated back to the respective values of V_2 they represent counting rates of 30–100 counts/s, instead of approximately 2000 counts/s. (The curve taken at 1.76 kv, which is above the dark-current 'knee', is neglected.) These results could be explained by repeated feedback, optical or otherwise, but only if p is smaller in the early stages of a multiple discharge than later on. It is not clear why this complication should occur.

An alternative explanation, suggested by a comment made by Dowling *et al.* (1956–57), is that the large pulses are due to positive ions produced by ionization of residual gas in the photomultiplier. If each positive ion shower causes a small number of electrons to be emitted from the photocathode, this number fluctuating statistically in accordance with a Poisson distribution, then the pulse-height distribution

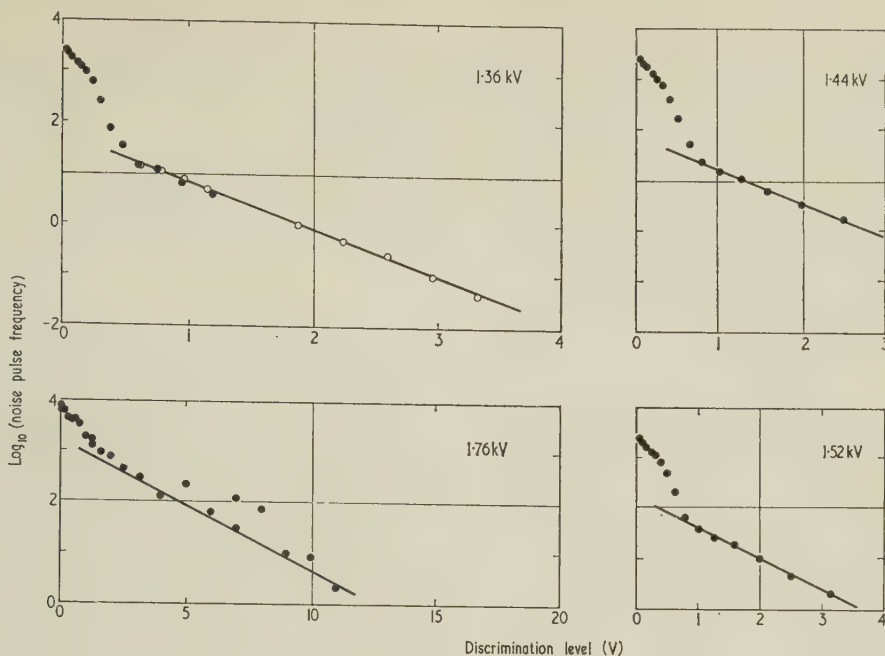


Fig. 4. Noise counting rates.

duced is likely to be generally similar to the pulse-height distribution due to single electrons emitted from the photocathode, except that the charges reaching the anode will be larger by a factor equal to the mean number of electrons leaving the photocathode at each ion shower. This is because both distributions are due to the cascading of multiplication processes in which Poisson distributions obtain (Wright 1954). It is assumed that the two pulse-height distributions are sufficiently similar, and that (owing to varying transit times) the positive ions of each shower do not reach the photocathode simultaneously so that the necessary time spread is obtained, then the curves of Fig. 4 can be explained as the sum of two superimposed distributions, each with an exponential lower portion. From the slopes of the respective straight-line and approximately straight-line portions of the 1360 v, 1440 v and 1520 v curves of Fig. 4 it can be seen that an extra multiplication of approximately five would be required in the 'positive ion' case. It is not clear, however, how cascaded Poisson distributions could produce a curve which is accurately exponential over 2.5 decades (the combined curve at 1360 v). A fuller discussion of the problem is given by Trott (1959).

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Some results obtained in developing a recording Geiger-counter x-ray intensity monitor

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Abstract

A single-beam monitor is described which samples the general background radiation scattered from an x-ray beam by a thin foil, and its behaviour compared to that of the main spectrometer counter receiving the K component from the same beam. Equal fractional changes of counting rate for monitor and main counter are observed when x-ray beam fluctuations are caused by changes in the x-ray tube current. No such simple relationship holds between monitor and main counter for changes in x-ray tube voltage. The response required of a counter for monitoring purposes is discussed briefly and the suitability of an end-window argon-filled Geiger counter established experimentally.

COUNTERS sensitive to x-rays are often used to make point by point surveys of x-ray diffraction patterns, different parts of which are measured at different times. Since the diffracted intensity is proportional to the incident beam intensity, such comparative surveys are only valid if the source is stable, or its variation known, during the period of the experiment.

Beam intensity variations due mainly to mains voltage fluctuations may be suppressed by expensive stabilizing equipment or monitored by means of an auxiliary counter system (Peiser, Rooksby and Wilson 1955, Hall, Arndt and Smith 1949, Hargreaves, Prince and Wooster 1952). A combination of both is probably essential for counter work of extreme accuracy.

The system described below is a single-window, single-beam continuous recording monitor in which a thin aluminium foil of thickness 0.001 cm scatters part of the general background radiation from the x-ray tube into the monitoring Geiger-Müller counter. Provided that the beam intensity fluctuations are due to x-ray tube current changes, the background sampled by the monitor is found to change in the same proportion as the $K\alpha$ component selected by crystal reflection for use with the main counter. No simple relationship holds for x-ray tube voltage variations.

Geiger-Müller counters suitable for monitoring

For the purpose of monitoring x-rays, counters should have high and constant quantum efficiencies for the wavelengths used and uniform sensitivity over a reasonable window area. Argon- and krypton-filled counters of adequate sensitivity for x-rays are now becoming available commercially.

Gillam and Cole (1953) have discussed practical difficulties in the accurate monitoring of x-ray beams. If very narrow slits are used in the collimating systems, or if the counters do not have a constant sensitivity across their windows, the

monitor will not necessarily indicate the fluctuations of the spectrometer beam. Several Geiger counters tested by them showed sharp sensitivity maxima and they concluded that, unless a counter of uniform sensitivity is available, accurate monitoring is not possible.

For the present monitor, tests were made on the sensitivity of Geiger-Müller counters especially designed for use with x-rays by 20th Century Electronics Ltd. Two B12 side-window counters filled with argon and an organic quenching agent to a total pressure of 70 cm Hg were found to have a constant sensitivity over a central region some 2 cm in length. The response (Fig. 1) along the diameter of the end-window counter EW3H filled with argon and a halogen quenching agent to a total pressure of 70 cm Hg indicates an annular region of constant sensitivity. Both counters appear to be suitable for accurate monitoring if properly positioned within the apparatus.

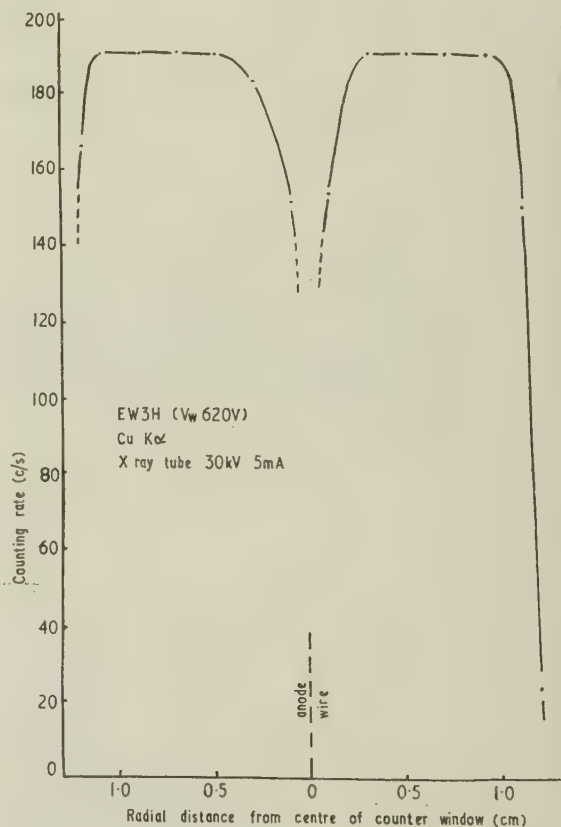


Fig. 1. Sensitivity along diameter of an end-window EW3H counter.

The monitoring system

The beam-sampling unit conveniently forms part of the crystal monochromator assembly. The aluminium scattering foil is placed over the entrance window to the monochromator, at is, before the beam falls on the crystal. The end-window Geiger counter EW3H is placed to receive the x-rays scattered from the foil at a glancing angle of about 20° to the foil. A short collimator ensures that the majority of the x-rays reaching the counter come from the foil at the angle indicated, and fall on the region of the counter over which a uniform sensitivity is found (Fig. 1).

The electronic recording system consists of a potential-reversing quench circuit followed by a background-reducing circuit (Patla 1960), pulse shaper, counting-rate meter and recorder, all supplied from highly stabilized power units. The input unit containing the quench circuit, linear pre-amplifier and cathode follower is situated at the x-ray machine thus allowing a short coaxial cable connection to the counter. The potential-reversing circuit is found to reduce the dead time of the counter from its normal value of $300 \mu\text{s}$ to a constant value of $30 \mu\text{s}$. The linear pre-amplifier and cathode follower make it possible to transmit the counter pulses through a long cable to the recording table.

During an investigation of the quantum efficiency of a proportional counter (Kiss and Patla 1959) a continuous record was made of the fluctuations of x-ray beam intensity using a pen recorder (Pen Oscillograph M942C, Southern Instruments Ltd.) rendered sufficiently sensitive by a potential locking-off method to detect 1% variation in counting rates. After an initial warming-up period for the whole apparatus about 30 minutes fluctuations of this order of magnitude were observed during experimental counting periods.

Discussion

The monitor may be used simply as an indicator and the x-ray intensity maintained constant, if necessary, by manual adjustment of the x-ray tube filament supply. If it is necessary to record monitor readings and apply corrections to experimental results, the relation between monitor and spectrometer counting rates must be known for the kind of fluctuations present.

The convenient continuous-monitoring system described above has the disadvantage that the monitor counter samples the whole of the x-ray spectrum, while the spectrometer receives only the crystal-selected $K\alpha$ radiation. It may not be assumed that alteration in the operating conditions of the x-ray tube will affect both counters equally, especially as the two main variables, current and voltage, have different effects on the x-rays produced.

The mode of generation of x-ray photons indicates that variation of tube current alone will cause a proportional variation of x-ray intensity over the whole emission spectrum, and hence both monitor and spectrometer should show the same relative variation of counting rate. This is the more important type of fluctuation in practice, as the tube current depends to a marked degree on the vacuum and the condition of the filament. An experiment conducted at constant x-ray tube voltage showed that the counting rates, recorded simultaneously, of both monitor and spectrometer counters are proportional to tube current I , and could be expressed in the form $n_1 = k_1 I$ and $n_2 = k_2 I$ respectively. Under these conditions it is easily seen that the relative changes dn_1/n_1 and dn_2/n_2 are equal, and thus the monitor readings indicate the relative fluctuations of the $K\alpha$ beam intensity.

The effect of variation of x-ray tube voltage on the behaviour of the monitor is less simple. The 'white' radiation does not necessarily change in the same way as a particular characteristic radiation. For instance, below 17400 volts no $\text{Mo } K\alpha$ will be generated while the monitor would continue to respond to the 'white' radiation. Furthermore, the dependence of the monitor counter efficiency on the wavelengths generated will affect the monitor readings, with no corresponding effect at the spectrometer counter receiving only $K\alpha$ radiation. Fig. 2 shows the monitor and spectrometer counting rates, corrected for counter dead time, as a function of x-ray tube voltage only, the tube current being constant throughout. Neither curve satisfies the requirement that $n = kI$, and the relative change of counting rates is markedly different in the two cases.

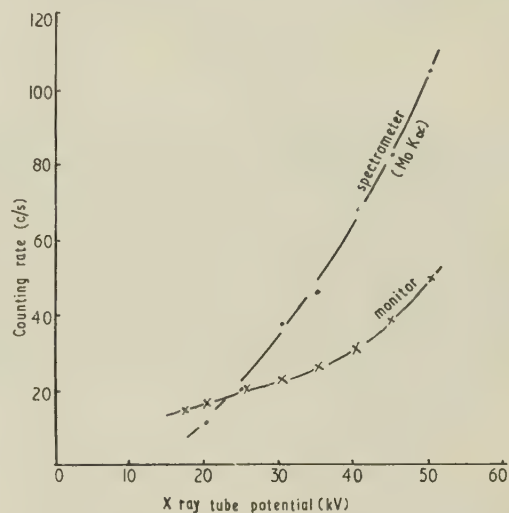


Fig. 2. Monitor and spectrometer counting rates for variation of x-ray tube potential.

X-ray tube current variations are more serious in practice than voltage fluctuations and the effects of the latter are largely avoided in the more complex monitoring methods using the characteristic radiations themselves. The simple system described above appears to be especially suitable for use with an x-ray machine which derives its e.h.t. from a constant-voltage transformer.

Acknowledgment

The authors wish to thank Mr. R. H. Humphry for his interest in this work.

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Small high-temperature vacuum furnace

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MS. received 8th September 1960

Abstract

A small high-temperature vacuum furnace, using tantalum as the heating element, is described. The main features of the furnace are its simplicity of construction, the absence of internal water cooling and the comparatively low power requirements (2.5 kW at 2200 °C).

Introduction

FOR both sintering and compatibility studies it was desired to heat cylindrical specimens, $\frac{1}{2}$ in. diameter $\times$ $\frac{1}{2}$ in. long, to 2000° C. A small vacuum furnace was therefore built, the main features of which are simplicity of construction, robustness and low power requirements. Of the three common refractory metals, molybdenum, tungsten and tantalum, molybdenum was rejected as a heating element material on account of its high vapour pressure at 2000° C (Campbell 1956) and, although tungsten has been used in similar furnaces (Alberman 1950, Kieffer and Benesovsky 1958, Rendall 1952), tantalum was preferred because of the ease with which it may be fabricated.

2. Description of furnace

General arrangement. The furnace is shown in Fig. 1. The container consists of a water-cooled copper cylinder, $4\frac{1}{2}$ in. inner diameter $\times$ 13 in. long, flanged top and bottom and fitted with end plates. The power leads are brought through the bottom plate and a quartz window, for temperature measurement, is fitted to the top plate. A 2 in. diameter copper pipe connects the furnace to a vacuum system. Pressure measurement is by a Philips gauge fitted to the connecting copper pipe, and temperature measurement is by a Leeds and Northrup optical pyrometer sighting through the quartz window. The underestimate involved in sighting through this window was found to be 20° C at 1900° C. The power supply is from a 4 kw, 8 v, continuously variable transformer.

The element. The element consists of a cylinder 1 in. diameter $\times$ $2\frac{1}{2}$ in. long, formed from 0.010 in. tantalum sheet by spot welding. The cylinder is slit in two diametrically opposite places for 2 in. of its length. The element leads are formed from five $\frac{1}{2}$ in. wide strips of 0.020 in. thick tantalum. These are spot-welded together, with the centre strip cut $\frac{1}{2}$ in. shorter than the remaining four. The tops of the leads are bent to $\frac{1}{2}$ in. radius, the element being fitted into the slot provided by the shorter centre strip and spot-welded in position.

Power leads. These are made from 3 in. lengths of Pyrotex magnesia-insulated cable. The centre rod is $\frac{1}{2}$ in. diameter and the outer tube $\frac{3}{4}$ in. outer diameter. The outer sheath is stripped to expose $\frac{1}{2}$ in. of the centre rod at each end to allow the fitting of connections. The cables are then brazed into $\frac{3}{4}$ in. holes set 3 in. apart in the copper base-plate, the arrangement being shown in Fig. 2. The

leads outside the furnace case are water-cooled by means of $\frac{1}{8}$ in. diameter copper piping. This is broken where electrical insulation is required by means of polythene tubing fitted with Wade P couplings. No water cooling is introduced inside the furnace chamber. The magnesia annulus of the Pyrotex cable is sealed with Araldite at each end to provide vacuum tightness. This simple arrangement has proved satisfactory, the tantalum element remaining ductile after prolonged exposure to high temperatures. The pressure reading has varied between 1×10^{-5} and 1×10^{-4} mm Hg when cold, rising to approximately 4×10^{-4} mm Hg when hot.

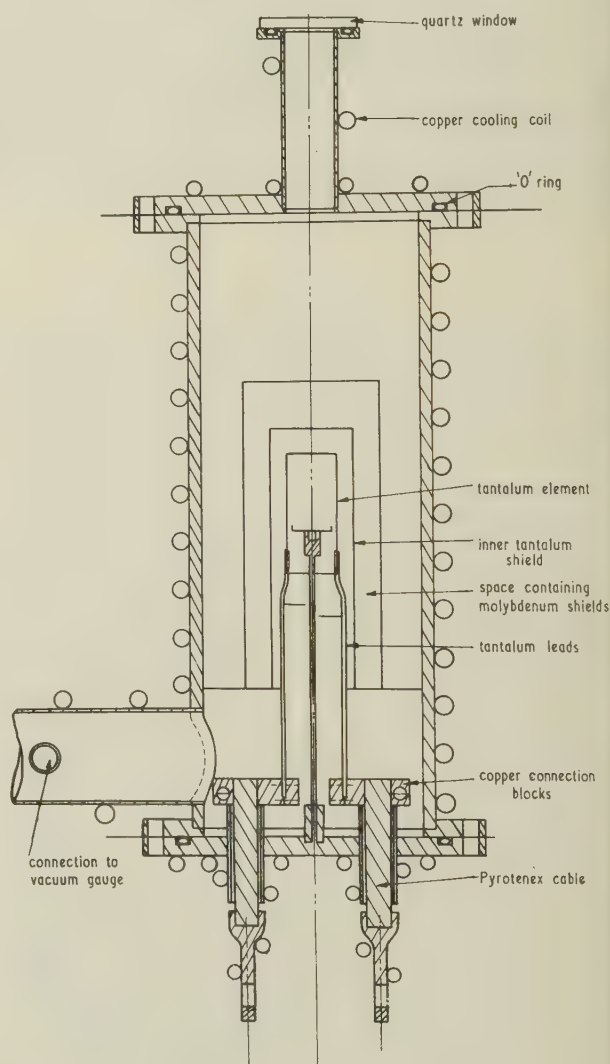


Fig. 1. General furnace arrangement.

Radiation shields. The radiation shielding is constructed in three sections, side, bottom and top. The cylindrical inner shield is made from 0.005 in. tantalum sheet and around this is fitted a four-turn roll of 0.005 in. molybdenum. This is dimpled on approximately 1 in. centres by a blunt punch to minimize contact between turns. The roll is tied with

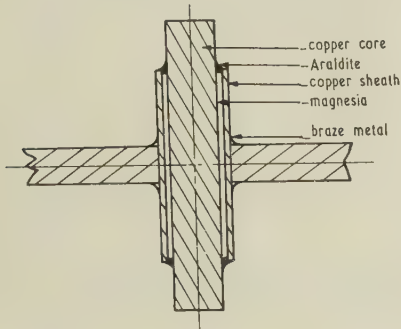


Fig. 2. Power leads to vacuum system.

tantalum wire, fitted over the inner tantalum shield and separated from it by three small tantalum lugs welded to the top of the inner shield. A second similar roll of molybdenum is also fitted and allowed to expand inside a 2 3/4 in. stainless-steel cylinder formed from 0.010 in. sheet. This cylinder is located centrally in the furnace by three pointed lugs. In this way, eight turns of molybdenum are fitted in a 1/2 in. wide annulus. The side shields rest on a 0.020 in. thick molybdenum plate raised 3 in. from the copper base-plate by three lugs. This molybdenum plate is provided with a central hole to allow passage of the leads and also the central specimen support. This hole is shielded by means of two tantalum baffles spot-welded to the element leads. The top shields consist of a nest of two tantalum and four molybdenum sheets separated by dimpling. These shields rest on the inner vertical tantalum screen and are held in position by the molybdenum screens. A 3/8 in. diameter hole is provided to permit temperature measurement.

3. Performance

The power required to maintain various temperatures up to 2200° C is shown in Fig. 3; at 2000° C the power required is 1.70 kw. The temperature response with time is shown in Fig. 4. The current was gradually raised to 300 A over two minutes and then maintained until the temperature became constant in approximately five minutes. Cooling from 2000° C to black heat requires 7 1/2 min. In Fig. 5 the power-temperature relationship of Fig. 3 is plotted logarithmically. Stefan's law states that the heat loss P from a radiating body is given by the expression:

$$P = k(T_1^4 - T_0^4)$$

where T_1 is the temperature of the body, T_0 is the temperature of the surroundings and k is a constant. As T_0^4 is small compared with T_1^4 (approximately 0.1%), T_1 should be proportional to the power input raised to the power 1/4. The actual slope obtained is 0.234, showing that the law is closely obeyed, the small deviation probably being due to conduction along the tantalum leads.

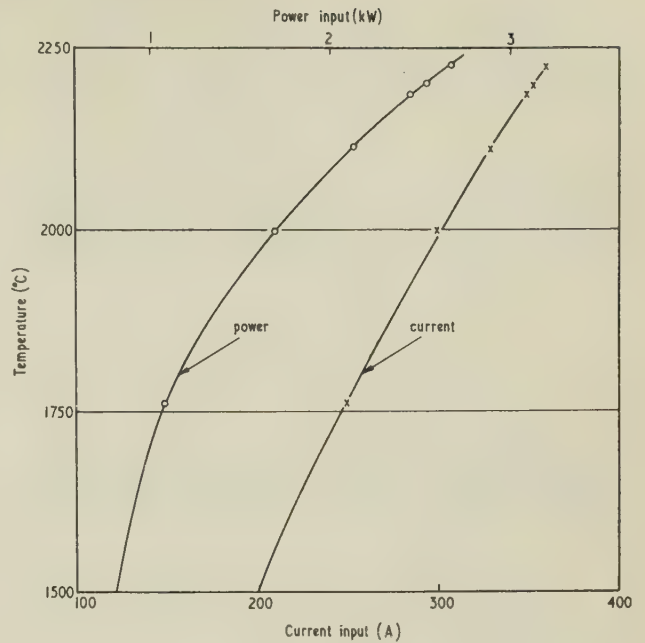


Fig. 3. Variation of temperature with power and with current input.

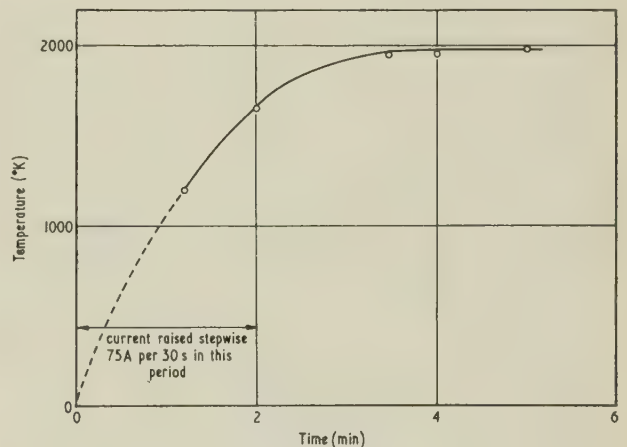


Fig. 4. Variation of temperature with time.

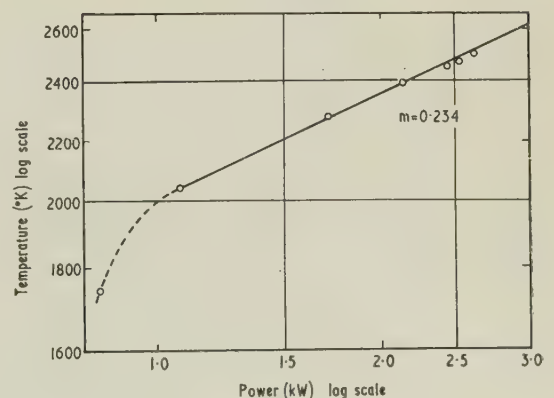


Fig. 5. Power-temperature relationship.

Over thirty experiments each of one hour duration have been carried out in the furnace at 1800° C. A small number of experiments have also been done at 2000° C. During this period the furnace has operated satisfactorily.

Acknowledgments

The authors are indebted to Mr. R. L. Bickerdike, Royal Aircraft Establishment, Farnborough, for suggesting the

dimpling of radiation shields, and to C. A. Parsons and Co. Ltd. for permission to publish this work.

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Calculator for solving electron irradiation problems

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MS. received 9th August 1960

Abstract

A discussion is given of the factors involved in the accurate radiation dosimetry of objects bombarded with initially mono-energetic electrons. It is necessary to match the incident electron energy with superficial density in the case of a parallel-sided target in order to attain uniform dose distribution. A preferable procedure is to employ the maximum electron energy available and to use a beam filter of suitable thickness, interposed between the electron source and (in contact with) the target. Such a combination minimizes the maximum overdose given.

Another concept described is that of average dose factor, which arises because of the asymmetry of the normal ionization curve.

Details of a simply made instrument are given, enabling electron dosimetry calculations to be made by a mechanical analogue of the normal ionization curve. It shows values for optimum electron energy, filter thickness required, and also for average dose factor once the superficial density of the target is known.

Introduction

A DESCRIPTION is given of the construction and operation of a mechanical calculator which provides data needed to ensure optimum dose distribution within electron-irradiated polyethylene. The variation of ionization within an object bombarded by mono-energetic electrons is such that it is possible to arrange an internal dose distribution which is symmetrical through the thickness; the object receives a certain level of dose throughout its bulk and an overdose which reaches a maximum in the centre. The optimum distribution of dose can be attained by variation of electron energy to match the superficial density of the object, or by the use of filters placed between the object and the electron source. The calculator may be used to determine suitable electron energies, filter thicknesses and extent of overdose for objects of known superficial density. It is simply constructed of Perspex and may be made with normal

laboratory facilities. Although the calculator was designed to provide data for polyethylene at incident electron energies between 1–2 mev, data suitable for other electron energies and targets could be incorporated in a similar instrument.

The uniform processing of materials by mono-energetic electron irradiation is in several ways a more difficult problem than that of x-ray or γ -ray treatment. The range of electron in matter is small, so it is difficult to ensure uniform dose distribution throughout the mass of an object under irradiation unless its thickness is only a small fraction of the electron range. Charged particle absorption depends upon the number of collisions with electrons in the target rather than the length of path, so target thicknesses are measured in terms of superficial density and are usually expressed in mg/cm². The maximum range of 1 million volt (1 mev) electrons in matter is of the order of 500 mg/cm² for elements of low atomic number. In an object of this thickness very few 1 mev electrons would reach the surface remote from the source. Other complications arise in that, although specific ionization increases with decreasing electron energy, the number of electrons available towards the maximum range is small through losses from scattering within the target, so that the dose level at the extreme electron range is very low.

The net result is that ionization within an electron-bombarded object of thickness equal to the maximum electron range is distributed as shown in Fig. 1. Data relating to the distribution of ionization in depth in aluminium, copper, lead and water for 0.3–1.5 mev electrons have been presented by Trump, Van de Graaff and Cloud (1946) and later for aluminium over the range 2–3 mev (Trump, Wright and Clark 1950); more recent data relate to aluminium and glass with 3 mev electrons (Davison, Goldblith and Proctor 1956). Ionization curves obtained for these materials were similar to that in Fig. 1 which applies to polyethylene (Cornish, unpublished data).

To obtain optimum uniformity of dose distribution within a parallel sided slab of material irradiated normally to one face, it is necessary to arrange that the ionization is the same

each surface so that the region of overdose is almost uniformly distributed about the central axis. For any given superficial density it is possible to select an electron energy that this can be done, as in Fig. 1. However, under these conditions the maximum overdose about the centre line is

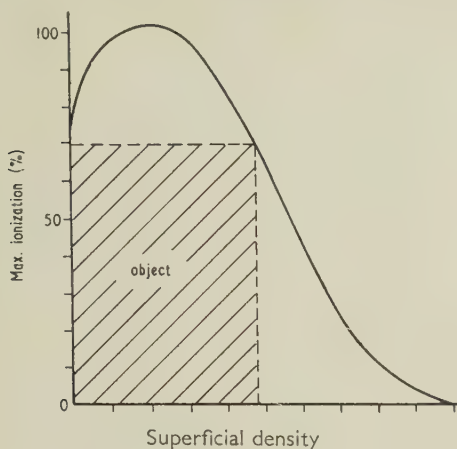


Fig. 1.

constant for each material and has a value for polyethylene of 43%. The amount of overdose may be minimized by increasing the electron energy, and hence the range relative to the superficial density of the object, and using a filter between the radiation source and object, to absorb some of the initial low ionization. The ionization distribution in such an arrangement is shown diagrammatically in Fig. 2.

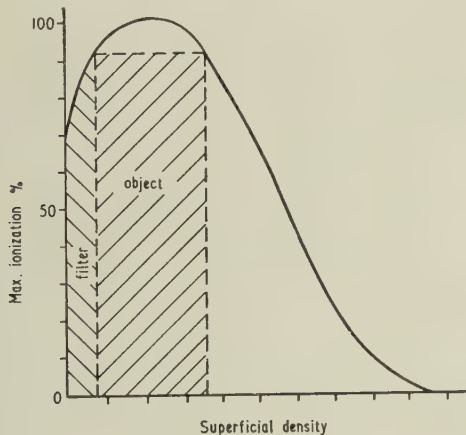


Fig. 2.

the overdose at the centre is thereby reduced and approaches a limiting value of zero as the sample thickness increases to zero.

The area under the curve of Fig. 1 is proportional to the total dose applied to an object with a superficial density equal to the electron range. Since the main area is towards the left of the ionization curve, it is evident that an object thinner than the maximum electron range receives more dose than its thickness relative to the maximum range would suggest. On integration of the curve in Fig. 1 a relationship has been obtained between the superficial density of the irradiated object and the percentage of the total potential dose absorbed by any thickness up to the maximum electron range. The

ratio of percentage of total potential dose absorbed to superficial density as percentage of maximum electron range is termed *average dose factor*, and varies from 1.0 to about 1.3 for polyethylene.

When irradiating a slab of material normally to the parallel surfaces, therefore, it is necessary that:

- (a) The amount of ionization (and hence dose level) at each face of the object is the same, so that the region of overdose is distributed evenly about the central axis. This condition is fulfilled by suitable selection of incident electron energy or by the use of a filter of the correct superficial density for some given higher electron energy.
- (b) The average dose factor must be calculated to correct for the superficial density of the object. Thus, if an object superficial density represents 29% of the maximum electron range, it has an average dose factor of 1.2, so the dose actually received by it is 1.2 times the nominal dose which would be applied overall to an object with a thickness equal to the maximum electron range.

In the case of objects thicker than the electron range at the particular energy used, the surface remote from the radiation source receives no radiation at all so the dose distribution varies from some value at one face to zero at the other. Within limits imposed by the available electron energy, this difficulty may be overcome by irradiating the object on both surfaces ('cross-firing') so that the total ionization, or dose, produced at the centre equals that at each surface. In this case there would be two zones of overdose within the sample, but the overall dose distribution would be symmetrical about the central axis. This condition may be optimized by suitable adjustment of the incident electron energy, but better uniformity of dose distribution may be attained by using as high an electron energy as possible and interposing filters to modify the distribution of ionization within the object. The arrangement would then be as in Fig. 3. The concept of average dose factor still applies in this case, but the value of superficial density should be taken as half the actual value in the calculations as irradiation is on both surfaces, that is, the sample thickness is effectively halved.

Description of calculator

Calculation of the parameters involved in electron dosimetry is simple but tedious. The method lends itself to mechanical treatment, and for this purpose the calculator shown diagrammatically in Fig. 4 was developed. Essentially the instrument is a mechanical representation in Perspex of the curves of Figs 1 and 3. These can be moved relative to each other as in Fig. 3; scales are provided to cover a range of conditions of incident electron energy and superficial density.

From the calculator may be found, by suitable movement of the scales:

- (a) The electron energy needed to produce the same ionization at each face of a plane object of known superficial density when irradiated on one surface.
- (b) The electron energy needed to produce the same ionization at each face and at the centre of a thicker object irradiated on both surfaces.
- (c) The filter thickness which must be interposed to attain maximum dose uniformity for an incident electron energy of 2 mev.
- (d) The percentage overdose and its position within the object.

In addition, the curve relating the average dose factor with superficial density for 2 mev electrons is engraved for convenience on the reverse side of the instrument. Also provided is the curve relating percentage of total dose absorbed with superficial density, so that average dose factor values may be calculated in the cases where a filter is used.

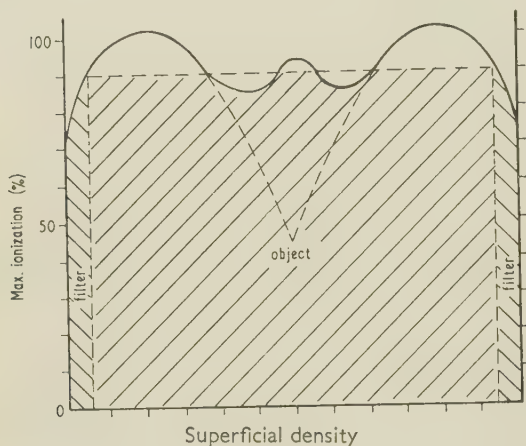


Fig. 3.

Construction of calculator

The instrument was built of $\frac{1}{8}$ and $\frac{1}{16}$ in. Perspex sheet, with $\frac{3}{4}$ in. diameter polystyrene rods slotted to act as runners for the moving parts, and a brass screw and bushes for the moving mechanism. Fig. 4 should be referred to in conjunction with the description.

A base *a*, which may conveniently be 10 in. $\times$ 6 in., is engraved with a representation of the ionization/distance curve for polyethylene, *x*, with an ordinate *E*. The base *a* is fitted with side runners *b* in which slides the smaller plate *c*. This is engraved, *y*, with the mirror image of the ionization curve and has an ordinate *A*. The plate *c* can be moved relative to *a* by turning the screw *d*. Thus the

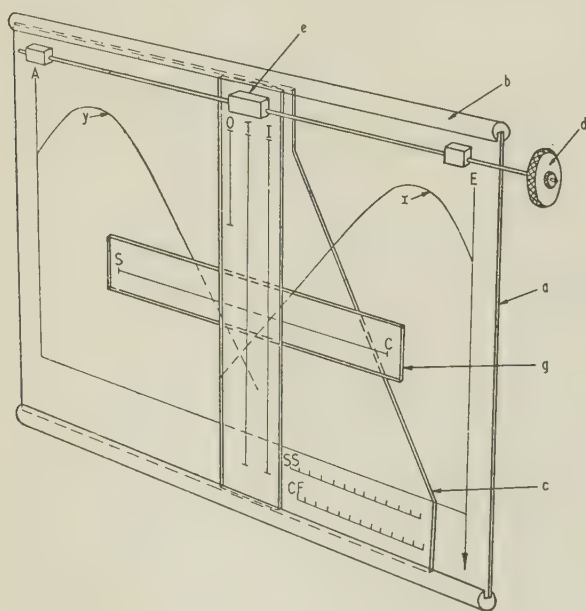


Fig. 4.

curve of Fig. 3 is reproduced with the facility of expanding or contracting the superficial density abscissa. The screw has a right-hand thread on one half and a left-hand thread on the other and runs through threaded bushes attached to *a* and *c*. Plate *e* is attached to a loose bush so located on *d* that it always covers the intersection of curves *x* and *y* by moving relative to *a* at half the speed of *c*.

Scales *SS* and *CF* are engraved on *c* in such a position that when intersected by *E* they show electron energy needed respectively to irradiate objects on one side or both sides to attain optimum dose uniformity without the use of a filter. The exact dimensions of these scales are dictated by the physical size of the instrument and by the distance chosen to represent the maximum range of the electrons available. In the instrument described, 2 mev was the maximum energy available and the curves *x* and *y* were drawn so that the maximum range at this initial energy in polyethylene was represented by 4 in. The scales are drawn in by inspection once curves *x* and *y* are located on *a* and *c*.

Plate *g* which slides freely up and down *e*, bears scale *S* and *C* having a common zero on scale *T*; this zero is always on the vertical line intersecting curves *x* and *y*. The scales represent superficial density values to be set when irradiating respectively on one or both faces of an object. Scale *S* ranges from 0–700 mg/cm² over a length of $3\frac{1}{2}$ in. while scale *C* covers the range 600–1600 mg/cm² over a length of $3\frac{1}{4}$ in.; below 600 mg/cm² cross-firing is not needed when 2 mev electrons are available. The exact physical size of the scales depends upon the dimensions of the abscissae chosen for curves *x* and *y*. In use, they are located under these curves to represent the superficial density of an object to be irradiated; the necessary incident electron energy is then given on scales *SS* and *CF* at the intersection of *E*.

Plate *e* is engraved with percentage maximum overdose values *O*, percentage ionization values *I* and a third scale giving the total percentage ionization value reached in the centre of an object irradiated on each side. Scale *O* ranges from 0–40% and represents the overdose at the centre of the object; scale *I* ranges from 30–100% and is the graduation common to both ordinates *A* and *E*; scale *T* has approximately double the values of scale *I* and is used for cross-firing calculations. Scale *O* is calibrated directly from *x* which is fixed by the dimensions of the curves *x* and *y*. As an example of calibration: suppose an object is irradiated so that the centre receives the maximum ionization possible while the outer surfaces receive 80% of that maximum. Then the overdose at the centre is $\{(100 - 80)/80\}100$, or 25%. Thus this value on the *O* scale is engraved opposite the 80% mark on the *I* scale. Values on the *O* scale are read off from the required position on the *I* scale, which in turn is read at its intersection with the line *SC*. Scale *T* is read at the intersection of curves *x* and *y*.

On the reverse of *a*, which is painted opaque white for added contrast, are engraved for convenient reference the curves relating both percentage of total potential dose and average dose factor with respect to superficial density.

Use of calculator

With an object with superficial density less than the maximum range of electrons available, the screw *d* is adjusted until the superficial density reading on scale *S* intersects *A*. Then the electron energy necessary to reproduce the conditions of Fig. 1 is shown at the intersection of line *E* and the *SS* scale. Where irradiation of both sides of the object is required, a similar procedure is carried out using the thickness

line on scale C and line E; the energy required is read from the CF scale where it intersects line E. The conditions of Fig. 3 are then reproduced so that the ionization value at the centre is equal to that on the outer faces.

Average dose factor values appropriate to each object are read from the curve on the back of the instrument; the dose theoretically delivered is multiplied by this factor to give the actual dose received.

When optimum dose uniformity is required the maximum available electron energy should be used. The maximum energy may be used to design the calculator; in the present case was 2 meV. In the case of an object irradiated on one side only, its thickness must mentally be placed symmetrically under the hump of curve y; to do this the screw d and scale g are moved simultaneously so that the zero of scale S cuts the right-hand side of the curve y and the superficial density value on the scale appropriate to the object cuts the left-hand side of the same curve. Then the filter superficial density required is represented by the distance on the S scale between the left-hand intersection with the curve and line A. This process reproduces mechanically the conditions shown in Fig. 2. The percentage maximum overdose at the centre of the object is given by the reading on the O scale at its intersection with the S scale. A value for the average dose factor of the object may be calculated from the dose-absorbed curve on the reverse of the instrument. If the superficial density of the filter alone is t_2 and of filter and object is t_1 , and if the respective percentages of total absorbed dose are f_1 and f_2 then the average dose factor for the object is

$$\{(f_1 - f_2)/(t_1 - t_2)\}R \times 100$$

where R is the maximum electron range at the energy selected. The procedure is a little different when optimum dose uniformity is required in an object to be irradiated on both sides, the total ionization value represented by the sum of curves x and y at their intersection (shown on scale T) must equal the surface ionization as shown on scale I. The screw d and the position of slide g are adjusted simultaneously keeping the appropriate superficial density value for the object on scale C on the right-hand side of the curve x. The instrument is set correctly when the reading on scale I, at its intersection with the CS line, is the same as the reading on scale T where it meets the two curves. Then the total ionization at the centre of the object is the same as the surface ionization as in Fig. 3. The position of the areas of overdose may be seen from the instrument, and the value of percentage maximum overdose is read from scale O. The filter superficial density needed is represented by the distance on scale C between curve x and line E. The value of average dose factor may be calculated from the dose absorbed curve in the case of an object irradiated on one side only, using the calculation a superficial density value half that of the object.

General

The calculator described was constructed for use with polyethylene objects irradiated with electrons from a 2 meV van de Graaff electrostatic particle accelerator. In practice

it has been found that an electron energy of less than 1 meV has seldom been needed so this value was taken as the lower limit on the energy scale SS and CF. Within these energy limitations, satisfactory uniform dose distribution can be obtained in objects with superficial density up to 620 mg/cm² when irradiated on one side only. By irradiation on both sides, objects with superficial density up to 1520 mg/cm² may be treated satisfactorily, but nothing is gained by double irradiation where the superficial density is less than 620 mg/cm².

Data appropriate to other materials of interest may be used in construction of the curves used on the calculator. The curves vary slightly for different materials, due probably to differences in electron scattering. In such cases it is necessary to obtain a curve relating ionization produced to depth of electron penetration and to establish how the ionization values add together in the centre of an object irradiated on both sides. It has been found (Cornish, unpublished data) that the sum of such values in terms of dose absorbed at the centre of an object is not necessarily arithmetical; sometimes more dose is received in the centre of the sample than would be expected from the individual doses applied, as in the case of water. In the cases of polyethylene and glass the dose in the centre is slightly less than would be expected. Such data are necessary for accurate construction of scale T.

It should be pointed out that only initially mono-energetic electrons have been considered; β -particles emitted from radio isotopes are not suitable for general radiation processing where uniformity of dose is required. Since radio isotopes emit a spectrum of β -particle energies up to a definite maximum, the ionization produced within a material by the β -particles has a very different distribution to that shown in Fig. 1. It has been found (Cornish, unpublished data) that no object can be treated so that each face receives the same ionization unless both faces are irradiated; where uniform dose distribution is desired the maximum β -particle energy and the superficial density need careful matching to avoid underdosing the centre.

Acknowledgment

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Very high speed dual-purpose image-converter camera

by F. H. GROVER, Atomic Weapons Research Establishment, Foulness, Essex

MS. received 29th August 1960

Abstract

A laboratory instrument which uses a commercially available image-converter tube as a fast shutter for very short exposure photographs of high velocity self-luminous phenomena is described. Exposure times of ten micro-seconds are obtained with pulses derived from a line pulse circuit having a coaxially constructed thyatron switch. The equipment may also be used for streak photography with a choice of sweep times in the range 1–25 μ s.

Introduction

PHOTOGRAPHIC exposures in the 10 ns(μ s) region were required for study of very high velocity phenomena encountered in experiments at the above establishment involving high-energy discharges in deuterium and other gases. This requirement was outside the range of existing practical cameras, but it had been demonstrated (Saxe and Chippendale 1955, Walker 1956) that photographic recordings of this order of exposure time were possible by use of inertia-less shutters. Of these, the image-converter tube was thought to offer the best approach to the problem since, with highly luminous phenomena, results could be obtained with existing commercial tubes; whilst there was the potential, in principle, of further development which would make high-speed recording possible at lower luminous intensities. Additionally, by use of suitable scanning coils, one-dimensional position-time or 'streak' records could be obtained.

Experiments carried out with commercially available

tubes gave useful results and a prototype apparatus for single-shot photography was constructed on the basis of the experimental method. After further experimental work the scope of the equipment was extended to include facilities for streak photography. In its present form (Fig. 1), the instrument consists of a dual-drive system, housed in a single mobile rack working off 240 v.a.c. mains supply, which operates a camera unit containing the image-converter tube and optical components. The latter unit is a modified version of a standard item developed at the Atomic Weapons Research Establishment, Aldermaston.

Image-converter tubes

There are few types of image-converter tube available commercially and these are in limited production. Differences between types are in the spectral responses of photocathode, fluorescent-screen materials and electron-optical magnification ratio between photocathode and screen. The tube used in this instrument is a Mullard ME1201AA which has a blue screen and blue-sensitive caesium-antimony cathode. The tube may be used as a triode but in this application it is connected as a diode, the grid and anode caps being strapped together.

The relative efficiency of an image-converter system can be expressed as a gain or loss factor if a comparison is made between film densities obtained by the image-converter system and by direct photography under comparable conditions. This factor includes the effect of the additional loss

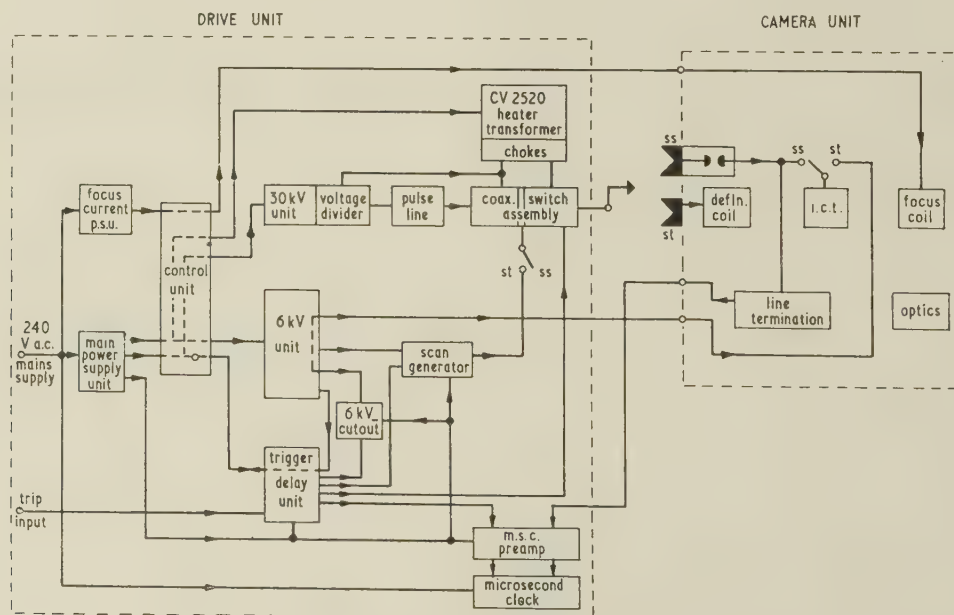


Fig. 1. Block schematic diagram of image-converter camera.

employed in the image-converter system for recording off screen and the lens should therefore be of the largest possible aperture. For the tube only, the ratio of light put intensity at the screen to that at the photocathode is a function of cathode sensitivity at the wavelength of the input, fluorescent screen efficiency, anode-to-cathode accelerating voltage, magnification ratio (and hence the focusing current). Assuming that lens apertures cannot be further increased, it is apparent that the only parameters which can be readily varied in order to improve the light output of a system using this type of tube are the e.h.t. accelerating potential and the focusing current. In practice, with standard tubes, reduced magnification at the screen, whilst giving increased brightness, introduces distortion with normal focusing methods. The method adopted, therefore, to obtain the increased sensitivity needed for short exposures by means of a very high e.h.t. voltage with focusing by a conventional solenoid coil.

Use of a voltage in excess of the d.c. rating is permissible only if the voltage is applied to the anode for periods of very short duration so that internal flash-over (causing destruction of the photocathode) is avoided. For use as an electron-optical shutter, the image-converter tube may be made to conduct transiently by gating pulses either at the grid (diode operation) or anode (diode operation). For use at very high voltages diode operation is simpler and this has the additional advantage of being the condition for optimum picture quality.

Conduction commences when a voltage of approximately 10 kV is applied between anode/grid and cathode of the E1201AA tube and it can be shown (Chippendale 1956) that, in conjunction with lenses of $f/1$ aperture, the gain factor for a single-stage image converter of this type is in the region of 0.5 for pulses of the order of 25 kV. Although no electron image is formed at anode voltages below the threshold value, and the tube may be normally considered as a closed shutter until pulsed, there may sometimes be a fogged region on the film caused by the passage of direct light rays through the tube. This results from small imperfections in the aluminized backing of the screen, and may be of importance where field lenses of large aperture are in use and light from the event being photographed is of high intensity for periods of relatively long duration. Tilting the axis of the image-converter tube with respect to the optical axis of the field lens reduces the amount of leakage light arriving at the film, but causes some distortion of picture shape on the record. Alternatively, a wire mesh or a perforated screen

interposed between the field lens and event, but as near to the latter as possible, reduces the total light arriving at the image converter and hence the leakage effects. In this case, the field lens is focused on the mesh and the resulting final screen image is composed of bright pinpoints of light which can, however, usually convey sufficient information. More complicated variants of this method are possible but have not been found necessary. Image converters with mosaic cathodes (Lunn 1957) have favourable leakage characteristics, but these are specialized non-standard devices.

Basic method of operation

(a) *Single-shot photography.* For single-shot photography, the switching requirement for the image-converter tube is a flat-topped fast-rising voltage pulse of large amplitude applied between anode and cathode. The focusing current is related to the peak value of the pulse, and the greater the departure from the ideal square shape, the greater are the effects of defocusing. A suitable pulse can be produced by discharging a length of coaxial line, charged to a high voltage, through a non-inductive switch into a load resistor. If the value of the terminating resistance is equal to the characteristic impedance Z_0 of the line and the line charging resistance R_c is very high, then the energy stored in the line will be dissipated in a single pulse without reflections. For a line voltage V , the resulting pulse has an amplitude $\frac{1}{2}V$ and time duration $2T$, where $2T$ is the time of travel of a wave which, as the switch is closed, passes up the line and back after reflection from the virtually open-circuited end at R_c .

Whilst this method has the attraction of simplicity, a disadvantage is the necessity for a charging source having a very high voltage V if the line output pulse is to have large amplitude; even the theoretical output of $\frac{1}{2}V$ cannot be attained in practice since any practical switching device introduces some attenuation. If, however, the charged line is discharged into another line having impedance Z_L higher than its own characteristic impedance Z_0 , the initial pulse produced will have an amplitude greater than $\frac{1}{2}V$, tending towards V as Z_L tends to infinity (Fig. 2). A difficulty here may be the occurrence of successive reflections due to the charged line being mismatched. Cancellation of such reflections may be effected by connecting to the terminating point P an additional coaxial line having the same length l as the charged pulse line. The end of this line is short-circuited, and secondary reflections travel back along the line to P, arriving out of phase with oncoming primary

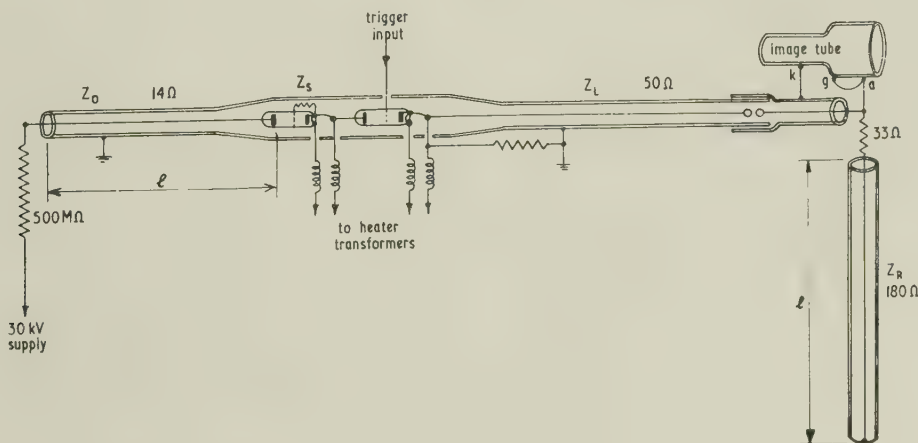


Fig. 2. Line pulse generator.

reflections from the open-circuited end of the charged line. The main pulse at P occurs before arrival of the secondary reflections, but thereafter cancellation takes place. For a large pulse amplitude, Z_L should be large compared with Z_0 and, additionally, since the line switching device has internal resistance R_S the line impedance Z_L should be large compared with R_S in order to minimize the voltage drop across the switch. In practice, the value chosen for Z_L is a compromise because of the opposing requirement for a low-line impedance so as to produce a rapid voltage rise across the capacitance of the image-converter tube. Similarly, the impedance Z_R of the reflecting line should be as high as possible compared with that of the output line Z_L for the largest amplitude of the pulse at point P, but a compromise value is chosen to preserve the pulse shape. Where focusing requirements for the image tube are not onerous, a greater pulse amplitude may be preferred at the expense of pulse shape by using larger values of Z_L and Z_R . However, by including an auxiliary pulse-sharpening gap at the line output, the rise time of the gating pulse may be made satisfactory for effective exposure times of 10^{-8} s (Fig. 3).

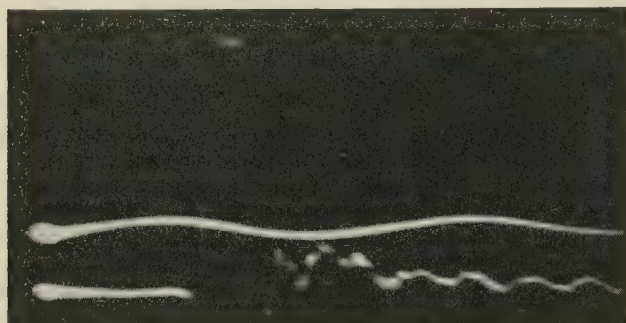


Fig. 3. Typical gating pulse produced across image-converter tube for single-shot photographs.

Amplitude 20 kv with 10 Mc/s calibration waveform superimposed. Residual peaks are below conduction threshold of image converter.

It is necessary to attenuate the secondary reflections to achieve exact cancellation of all voltage peaks after the first. The need for attenuation arises because reflections from the secondary line Z_R are of larger amplitude than the succeeding primary reflections which they are intended to cancel. Insertion of a resistor R in series with the secondary line attenuates the amplitude of its reflections to the correct level. The value of R can be determined experimentally and for the line impedances quoted is about 33Ω .

(b) *Streak Photography*. In this technique, a small element of the whole field of view is focused on to the photocathode by way of a narrow adjustable slit. Electrons emitted from the cathode are magnetically focused forming a beam which produces a magnified image of the slit at the image-converter tube screen. This beam may be deflected by a varying magnetic field produced by suitable deflection coils; about 2000 ampere-turns are required to deflect the beam across the image-converter screen, the actual figure depending upon coil position and dimensions and the focusing current. As it is necessary to keep inductance very low where fast sweep times are required, the scan coils can have only a small number of turns and, consequently, the current passed through them must have a high peak value. For this reason, a high-current thyatron is the most convenient means of switching current through the scan coils, and one of the pair incorporated in the single-shot circuit is used (see Fig. 1).

The basic circuit is simple, consisting essentially of a capacitor charged to a predetermined level, the hydrogen-filled thyatron type FX219 (by the English Electric Valve Co., Ltd.) and the deflection coils.

It is difficult to produce fast sweep times with the standard ME1201AA image converter because of the damping effect of the copper shielding around the cathode end and also of the grid cone structure. An improvement in speed is obtained if the scan coils are sited centrally around the tube, rather than in the usual physically more convenient positions around the ends of the tube. With the simple circuit outlined, a single half-cycle of resonance between coil and capacitor takes place with, however, a tendency for considerable ringing to occur, particularly on the rising front of the current waveform. The inclusion of a damping resistance is undesirable as it reduces sweep speed, but a pair of earthed thin copper bands encircling the turns of the sweep coil is effective in reducing ringing without materially affecting the sweep speed. In particular, on the trailing edge of the current pulse, spurious effects are eliminated by this means. The rate of fall of current, moreover, is almost linear thus giving an approximately linear sweep time-base for deflecting the electron beam across the fluorescent screen. It is advantageous therefore to synchronize the beginning of a luminous event with the decay rather than the rise of the deflection current pulse, and although the synchronizing operation is thereby rendered somewhat more difficult, the technique has been successfully applied in this instrument.

The scan coils are in the form of two series-connected halves, each having six turns. A distributed method of construction is not practical with a small number of turns and, in practice, simple undistributed saddle windings of mean length 5.5 cm and diameter 18 cm are used. With these coils, results obtained have been satisfactory for the purposes of the programme intended for this equipment. With a charging voltage of 5 kv and pulse capacitance of $0.1 \mu\text{F}$, a complete sweep takes place in $1.5 \mu\text{s}$ (Fig. 4). This speed has been chosen arbitrarily for the normal fastest sweep range in this equipment, but faster sweep times can be obtained by using an increased charging voltage. (In this case to obtain sufficient screen brightness it becomes necessary to have a higher anode voltage for the image converter than the 6 kv normally used for 'setting up' and 'streak' operation of the equipment. This involves connecting the tube as a triode, keeping the grid at the 6 kv level whilst operating the anode at voltages up to 15 kv. Under these conditions sweep times as short as $0.5 \mu\text{s}$ may

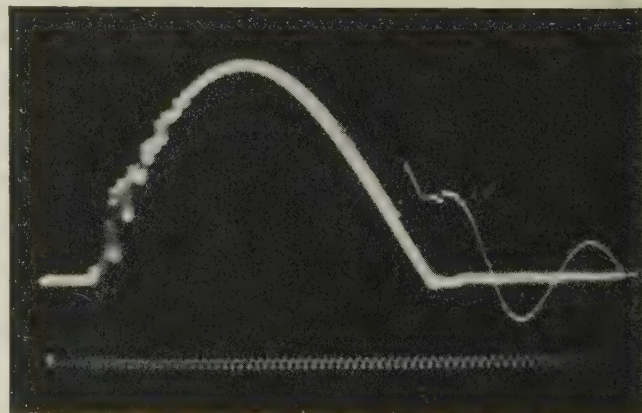


Fig. 4. Current waveform for $1.5 \mu\text{s}$ streak range with event-monitoring waveform and 10 Mc/s calibration waveform superimposed.



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56UVP As 53AVP but with quartz end window to give sensitivity to ultra-violet.

56AVP Eleven stage tube with 11 mm diameter photocathode for flying spot scanners.

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56UVP As 56AVP but with quartz end window.

57AVP Eleven stage tube with large photocathode 200 mm in diameter.

58AVP Fourteen stage tube with 110 mm diameter photocathode. This tube has a tetrode input system giving spreads in transit time over the photocathode of 10^{-9} s.

150AVP General purpose ten stage tube with 32 mm diameter photocathode.

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employed.) Using the normal charging voltage of 5 kv for the scan generator and diode connection at 6 kv for the image converter, two other slower ranges with nominal sweep times of 5 μ s (Fig. 5) and 25 μ s are available by operating a

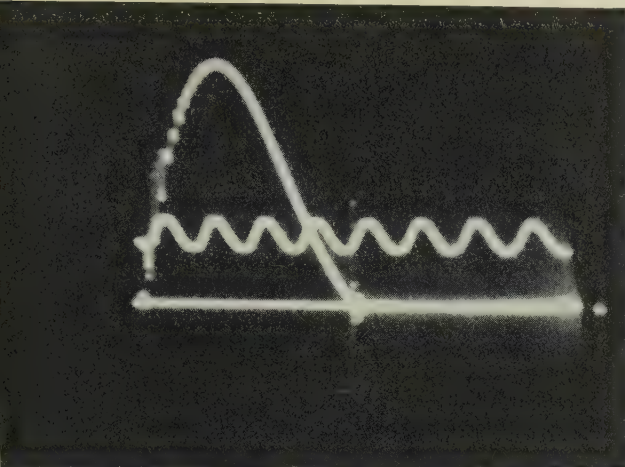


Fig. 5. Current waveform for 5 μ s streak range, with e.h.t. cut-off pulse monitoring waveform and 500 kc/s calibration waveform superimposed.

range switch which selects an appropriate combination of pulse capacitor and series resistance. Under this system, the slower ranges tend towards an exponential sweep law, but this is not usually disadvantageous.

Description of prototype equipment

The complete instrument consists of two interconnected units. In the camera unit, a field lens of short focal length and large aperture produces an image at the photocathode for single-shot applications. For streak photography, an adjustable slit and lens assembly is interposed between field lens and photocathode. A conventional oscilloscope type camera with a Wray f/1 copying lens is used to record off the screen of the image-converter tube on to Ilford 5G91 film.

The functions of the drive unit are to provide the voltage pulse of large amplitude and short duration required for single-shot operation of the image converter and, alternatively, for streak photography, the heavy current pulse required by the scan coils. The pulse-generating circuits, e.h.t. and power supplies required for these functions are contained in the drive rack together with focus-current supplies and sub-units providing control, triggering, delay and monitoring facilities.

The large gating pulse for single-shot operation is produced by charging a short length of low-impedance coaxial line to high voltage through a high resistance and then discharging the line through a special thyatron switch assembly. The resulting impulse is fed, via a length of coaxial line of higher impedance than that of the charged line, to a spark gap the far side of which is connected to the line-terminating arrangement described earlier and to the image-converter anode. The whole circuit, including the thyatron switch assembly and spark gap, is of coaxial construction and it is possible, by optimum adjustment of the pulse-sharpening spark gap, to produce a very fast rising pulse at the image-converter anode having small jitter time relative to the thyatron triggering input pulse. The thyatron switch consists of two FX219 hydrogen thyatrons in cascade, mounted coaxially in a cylindrical copper housing tapered at either end to the

physical dimensions of the coaxial lines. Various arrangements of this kind for millimicrosecond pulse applications have been described (Hurd 1954, Lewis and Wells 1959). With the inductance of the system minimized in this way the factors limiting the rise time of the pulse are the cathode emission of the thyatrons and time constant due to the image-converter tube capacitance. The effective length l of the charged line is such that the gating pulse is of 10^{-8} s duration. Longer exposures may be obtained by substituting appropriate line lengths. The resolution obtained for single shots of 10^{-8} s is equivalent to 4 lines/mm at the photocathode which is adequate for work with shock tubes.

On 'streak' operation, one of the FX219 thyatrons forms part of the scan generator circuit into which it is switched by relays. A 30 kv section and a 6-12 kv section supply e.h.t. for single-shot and streak requirements respectively. The output voltage in either case is indicated by an e.h.t. meter.

The main thyatrons are fired by a fast pulse produced by a trigger delay unit. This unit is common to both single-shot and streak systems and the trigger output pulse can be initiated by external positive, negative or short-circuited inputs or by a manual trip switch. The trigger output can be delayed by any desired time interval from trip input up to a maximum of 25 μ s. The overall jitter of the system from trip input to final camera pulse is of the order of $\pm 0.025 \mu$ s, and the total of delays in triggering, including both inherent and inserted delays, is monitored by a microsecond clock. The latter unit consisting, in effect, of a calibrated time-base, gives a voltage reading proportional to the period for which the time-base is allowed to run; the meter dial can be calibrated in microseconds and gives a discrimination of better than 0.01 μ s on the shortest range. Two pulses of like polarity and rise time are required for initiation, the reading given by the instrument being the time interval between these inputs. By arranging that the 'start' pulse coincides with the initiation of an event and the 'stop' pulse with the instant of gating the image converter, a single-shot photograph can yield, in conjunction with the microsecond clock reading, velocity as well as qualitative information. In general, the clock provides a useful means of arranging that the camera operates after a chosen time interval relative to some known event or marker pulse.

As it is desirable to limit the running time of certain parts of the equipment, the supplies involved are distributed via a control section. This unit provides automatic control of switching sequence, monitored by appropriate indicating lamps, and also contains manually operated system switches which select the mode of operation required for the equipment and sweep-speed range for streak photography. There are three modes of operation for the equipment designated, 'Set-up', 'Streak' and 'Single-shot' and appropriate supplies are switched to the image-converter tube for optical setting up, to scan generator or to line pulse generator respectively. The e.h.t. voltage supply for set-up and streak standard ranges is 6 kv, whilst the gating pulse amplitude for 'single-shot' is dependent on the setting of the 30 kv unit output-voltage control and on line impedances used, but is normally in the range 10-20 kv for highly luminous events. In order to prevent unwanted exposures on streak records, it is arranged that the image converter e.h.t. is pulsed off immediately after completion of a scan. The circuit which performs this cut-off function can also be used to provide a means of sweep-speed calibration by modulating the brightness of a sample trace.

The most frequent requirement in streak photography is for either a horizontal or vertical slit aperture relative to a

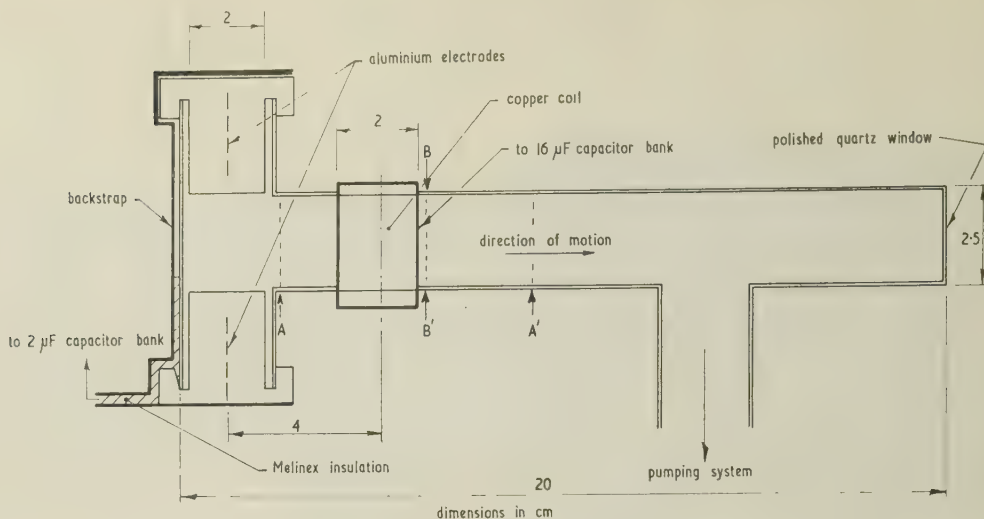


Fig. 6. Diagram of quartz apparatus.

An electromagnetically driven shock wave is produced in this T-shaped quartz tube when a 2 μF, 10 kv capacitor is discharged across the end electrodes. Ionized plasma behind this shock front travels along the horizontal limb around which is a wide single-turn coil. Magnetic compression of the plasma occurs when a synchronized current pulse of 5×10^5 A passes through the coil (Figs 7 and 8).

shock tube (Fig. 6) or similar device (Wright 1959), but intermediate angles may sometimes be required. Change of slit angle and corresponding alteration in the direction of sweep can be achieved by use of rotatable scan coils and a demountable-slit optical assembly. However, scan coil construction and camera operating procedure are simplified if the camera body has fixed coil and slit positions and is itself turned through any required angle. Hence this method has been adopted in practice.

Some applications

Figure 6 shows one form of apparatus used for generation of intense shock waves. It consists essentially of a T-shaped quartz tube having electrodes connected through the ends of the vertical limb and a single-turn external copper coil around the horizontal limb.

The tube is filled with deuterium at a pressure of about 1 mm of mercury, and the electrodes are connected to a low

inductance capacitor bank via a special low inductance switch and a copper backstrap very near and parallel to the vertical limb. The most effective low-inductance switch takes the form of a small explosive charge mounted on top of a conductor/insulator/conductor sandwich and when this is fired a very heavy current discharge occurs in the gap between the electrodes. This current is also flowing in the backstrap and under the action of the large forces produced the conducting plasma is driven into the horizontal limb of the tube.

As the shock front passes through the region of the tube surrounded by the large single-turn coil a very large current is caused to flow through the coil by the synchronized discharge of a second capacitor bank. The effect of this is to compress, or pinch, the plasma thus adding to the effects of shock heating. Fig. 7 which is a single-shot photograph shows the effect on plasma which has just emerged from the coil in its passage along the horizontal tube and covers the field of view designated AA' in Fig. 6. Effective exposure time for this record was 10 ns (mμs).

Figure 8 is a streak record of a similar event showing con-

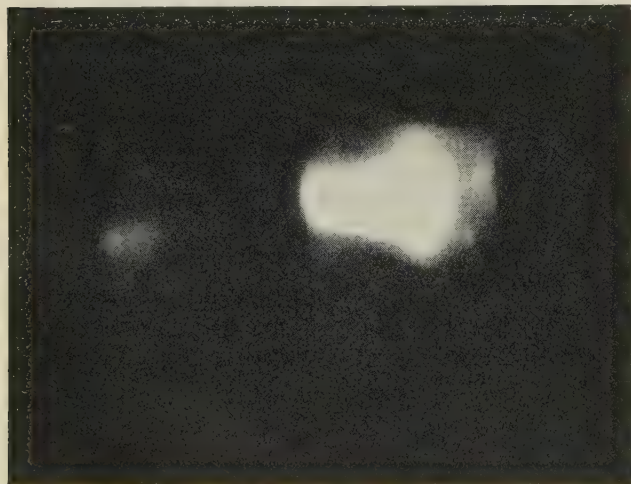


Fig. 7. Pinch-effect in deuterium at 1 mm pressure single-shot photograph of region 'AA'.
Velocity of shock front, 3.6 cm/μs.

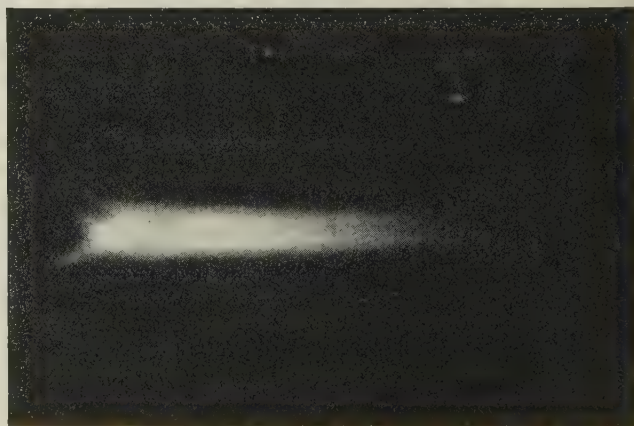


Fig. 8. Streak record of discharge in deuterium viewed through slit at a position corresponding to region 'BB'.



Fig. 9. Streak record of electromagnetically driven plane shock waves in deuterium approaching a region of collision at centre of a symmetrical double-ended device.



Fig. 10. Streak record of shock phenomena in a device similar to that of Fig. 9 obtained from A.W.R.E. S4 mirror streak camera. Included for comparison with Fig. 9. (Shock speeds 8 cm/ μ s)

ditions in an element of the tube designated BB' in Fig. 6. The time duration of this record was 5 μ s.

Another form of apparatus for production of very strong shocks consists of an airtight chamber containing parallel plane electrodes 4 cm long and 2 cm apart. These electrodes are connected to a large capacity high voltage capacitor bank via a low inductance switch and the device is filled with deuterium at low pressure.

When the switch is fired, simultaneous current sheet discharges occur at the minimum inductance positions at either end of the chamber. Under the action of electrodynamic forces set up due to a backstrapping configuration two plane shock waves are impelled towards the centre of the chamber where they collide. Fig. 9 shows an image-converter streak record of such an event. On the record the shocks can be seen to collide in the central region of the chamber the time scale here being about 0.25 μ s from start of the event to collision.

Figure 10 is a streak record of a similar event produced by the high-speed S4 mirror streak camera and is included for comparison with Fig. 9.

The image-converter camera has been used with satisfactory results to record events in various other devices of a similar nature and for the photography of transient shock phenomena produced by firing high explosive charges.

Conclusion

Simpler techniques for both single-shot and streak photography and recording at lower light levels will be possible when improved versions of image converters become generally available. For the present, this apparatus provides a means of obtaining accurately synchronized short-exposure photographs of highly luminous events using a currently available type of tube. For the specific application to self-luminous phenomena in gases, the optical requirements are not exacting, any limitations on resolution associated with the use of image converters are not of prime importance and with the system described effective exposure times of 10^{-8} s may be obtained.

Acknowledgments

Acknowledgment is made to the Director of the Atomic Weapons Research Establishment for permission to publish this paper, to Dr. R. F. Saxe of Queen Mary College, London, for valuable suggestions made at the outset of the project and to Mr. G. H. Lunn of A.W.R.E., Aldermaston, for much helpful advice and practical assistance on many occasions. Thanks are also due to Mr. C. S. Speight of A.W.R.E., Foulness, who designed a simplified version of the microsecond clock and to colleagues who assisted in development and construction of the camera drive units.

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Flat-field microscope objective

by C. G. WYNNE,* B.A., Ph.D., F.Inst.P., Wray (Optical Works) Ltd., Bromley, Kent

MS. received 16th September 1960

Abstract

The heavy field curvature found in the usual type of microscope objective of numerical aperture 0.65 is shown to be amenable to correction without complication of the basic five-glass form of construction. The relevant aberration theory is discussed, and numerical data are given for an N.A. 0.65 objective of $\times 40$ magnification with substantially flat image field.

THE form of optical construction in general use for microscope objectives of numerical aperture about 0.65 is shown in Fig. 1. Such objectives have been in use for over a century; the design arose historically by taking a Lister type of objective consisting of two cemented doublets, each corrected for spherical aberration and, approximately, for coma, and adding to this system an Amici lens, having a plane surface facing the object and its other, deeply curved, surface in the aplanatic condition for rays from an axial object point. This Amici lens has the effect of increasing the numerical aperture of the system by a factor of n^2 , where n is the refractive index of the Amici lens, without affecting the aplanatism of the system if the plane surface coincides with the object plane, or is eliminated optically by a homogeneous immersion system. The Amici lens introduces some chromatic aberration, which can be corrected by chromatic overcorrection of the rest of the system, and for a dry objective with an air-space between the object and the plane surface, this plane surface introduces some spherical aberration and coma, which again can be corrected by modification to the two doublets.

Most microscope objectives of this type in common use today appear to depart little from designs achieved by the procedure outlined above; they employ a plane surface adjacent to the object and the two doublets are each nearly aplanatic. Such objectives can give a high degree of correction of spherical aberration and coma, but they have inherently large field curvature and astigmatism. The maximum field angle of microscope objectives is so small (about $\pm 3\frac{1}{2}^\circ$) that the primary aberration coefficients give an adequate description of field curvature and astigmatism; the curvature of field in the sagittal and tangential sections are then given by $P + S_{III}$ and $P + 3S_{III}$, where P is the Petzval sum and S_{III} the Seidel astigmatism coefficient. For these objectives, P generally has a value of about 1.1 times the power of the objective, and S_{III} is often of about the same size. With these values, for a $\times 40$ (8 mm) objective of N.A. 0.65, giving a primary image of about 20 mm diameter, the first-order undercorrect sagittal field curvature would give a wave-front aberration greater than one half wavelength (twice the 'depth of focus') at a field diameter above 6.0 mm, and the first-order undercorrect tangential field curvature would do this outside a 4.2 mm diameter field. These figures correspond to what is observed in most objectives of this type.

A number of microscope objectives with reduced or corrected field curvature have been designed using more complicated optical systems; for example, by the addition of one or more thick meniscus lenses on the image side of the basic lens form shown in Fig. 1 (Zeiss 1937, Jenaer

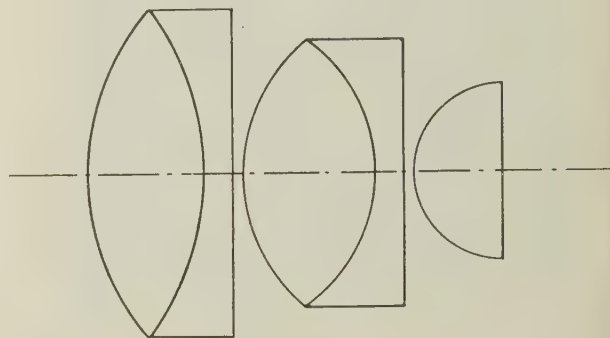


Fig. 1. Optical construction for microscope objectives of N.A. 0.65.

Rundschau 1956). It appears, however, that a flat field can be achieved without additional complication of the basic five-glass form if full use is made of all the variables of the system; as stated above, this field-flattening is simply a problem of first-order aberration correction.

The primary astigmatism can readily be reduced to zero by the method adopted in Petzval lenses of using a front doublet (at the image end) with substantial primary outward coma, which is corrected by equal inward coma in the rear doublet and Amici lens. Smaller primary coma residuals are needed for astigmatism correction if the two doublets are separated, but this necessarily increases the Petzval sum of the system. Correction of the Petzval field curvature is more complicated. Since the cemented surfaces must be divergent, to give the overcorrection of spherical aberration necessary to correct the undercorrection of the rest of the system, the convergent elements of the doublets must be of lower refractive index than the divergent elements; and to keep the zonal spherical aberration small it is desirable to make the index difference at the cemented surfaces as large as possible. There is, therefore, little possibility of reducing the Petzval sum by choice of glass for the two doublets. Some small Petzval sum reduction can be achieved by raising the index glass for the Amici lens, but since it is desirable in microscope objectives to use only glasses that are relatively immune to staining, the choice of glass here too is restricted. It follows, from primary aberration theory, that the only place in the system where a substantial overcorrect Petzval sum contribution can be gained is on the surface of the Amici lens adjacent to the object, where the incidence height of rays from an axial object point is small, and a concave surface, giving an overcorrect Petzval sum, therefore makes little contribution to the total power of the system. But using a concave surface in this position in place of the usual

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plane surface gives undercorrect astigmatism, and the ratio of the changes of S_{III} and P is, in the normal form of lens, substantially the same as that given by a separation of the two doublets, so that simultaneous correction of both is not possible by the use of these two variables. However, the change of S_{III} consequent on a separation of the doublets depends on the distribution of aberration between them, while the change in P depends on the distribution of power, decreasing as the power of the front doublet is reduced. By adopting a form of lens in which the power of the front doublet is much lower than is usual, that of the second doublet being correspondingly increased, the relative rate of change of P and S_{III} resulting from increasing the doublet separation can be altered, so that simultaneous correction of P and S_{III} becomes possible using this variable, together with that involved in giving the Amici lens a concave surface facing the object. Together with these changes, the shapes of the lenses must, of course, be altered in the usual way to give correction of the other aberrations. This leads to a form of lens where the distribution of aberrations differs considerably from the traditional ones with their near-aplanatic doublets. In order to keep the zonal spherical aberration within the small acceptable limits, the overcorrection of primary spherical aberration, necessary to correct the undercorrection of the rest of the system, must be distributed approximately equally between the two cemented surfaces so that, in the fully corrected field-flattened systems, the front doublet, of reduced power, has heavy overcorrect spherical aberration as well as outward coma and the central doublet has heavy undercorrect spherical aberration; these are corrected in the system as a whole.

It was stated above that the primary aberration coefficients give an accurate representation of the aberrations of astigmatism and field curvature over the small field angles of microscope objectives; this refers to these aberrations calculated along a principal ray through the nodal points of the lens. In objectives of this form there is always present a higher-order overcorrect oblique spherical aberration which becomes significant at the edges of the field. The effect of this is that the best state of correction is achieved at a small residual of undercorrect Petzval sum (about 0.3 of the power) is left in the system, to balance the overcorrect oblique spherical aberration.

The Table gives numerical data for a design of flat-field microscope objective of N.A. 0.65 and magnification $\times 39.3$ derived by the procedures described above. Dimensions are given in millimetres, ϕ being the clear diameters, r the radii, given serially from the front (image) end (following the usual sign convention that a positive radius is one convex to the front and a negative one is concave) and d the axial separations. The Petzval sum of this objective is equal to 0.308 of its power. The chromatic correction of this design is similar to that of traditional objectives; it has the usual secondary spectrum errors and chromatic difference of magnification (normally corrected by a compensating eyepiece) which appears to be uncorrectable in a lens of this form of construction with the present range of glasses. The axial spherical aberration for helium-d light gives a departure of the emergent wave front from sphericity within ± 0.04 wavelength, and the maximum sine condition error is under 0.1%. At the edge of the field of $\pm 3\frac{1}{2}^\circ$, the meridian section of the aperture is vignetted to about 80% of its axial value. Over the vignetted aperture, both the meridian plane and secondary plane sections of the emergent wave front lie almost wholly within 0.25 wavelength of a sphere centred in the axial plane of best focus.

Numerical data for a flat-field microscope objective of N.A. 0.65

ϕ	r	d	n_d	v
6.38	± 14.087			
	$- 6.016$	3.073	1.5477	45.6
6.24	$- 24.316$	0.866	1.7580	26.7
		8.390		
4.31	$+ 4.776$	3.061	1.5406	59.5
	$- 3.888$	0.762	1.7580	26.7
3.11	$- 7.529$	0.025		
		1.924	1.6132	56.8
2.52	$+ 1.832$	0.3902		
		0.180	(cover-glass)	
1.02	$+ 1.342$			
	∞			
	∞			

Front focal distance 179.8

The working distance of 0.39 mm between the cover-glass and Amici lens is shorter than is commonly found in microscope objectives of this specification, but is not impracticably short. The design can be modified to give a longer working distance, at the expense of a slight loss of field-flatness.

An objective of magnification $\times 40$ and N.A. 0.70, of design similar to that given in the Table, has been constructed by Messrs. C. Baker Instruments Ltd. Fig. 2 shows a wave-

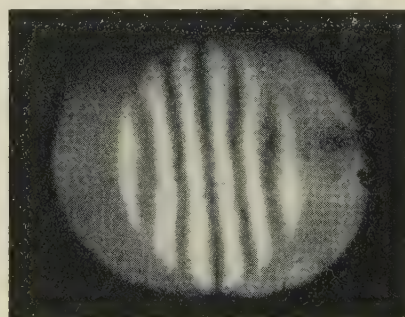


Fig. 2. Wave-front shearing interferogram.

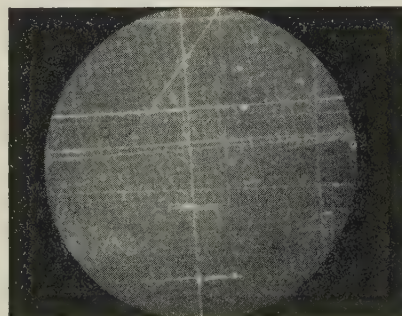


Fig. 3. Scratches on a metallized mirror photographed with a flat-field objective of N.A. 0.70 and magnification $\times 40$.

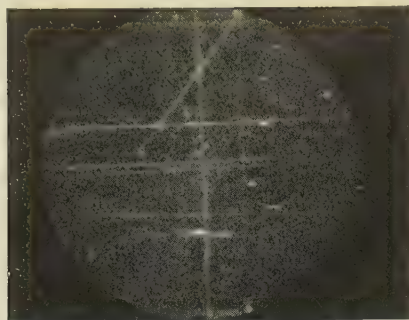


Fig. 4. The same object as in Fig. 3, but taken with an objective of the usual form.

front shearing interferogram of the axial imagery of this lens. Fig. 3 is a photograph of fine scratches on a metallized mirror taken with this flat-field objective, and Fig. 4 the same object imaged by an objective of the usual form.

Acknowledgment

I am indebted to Messrs. C. Baker Instruments Ltd. for the photographs (Figs 2-4).

A patent application has been made covering objective embodying the principles described in this paper.

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Uni-axial pantograph

by J. C. BARNES, M.Sc., Radio and Electrical Engineering Division, National Research Council, Ottawa, 2, Ontario, Canada

MS. received 16th September 1960

Abstract

A description is given of a simple and effective drafting instrument for changing the scale of a graphical trace along one axis only, leaving the other axis unaltered.

THE function of this instrument is to change the scale of a graphical trace along one axis only, leaving the scale of the other axis unaltered. It should be noted from the outset that this is not a mathematically perfect instrument. Its virtues are simplicity, and an error so small that for visual comparison purposes it is negligible.

In essence, the instrument shown in Fig. 1, consists of two ellipsographs linked together, back to back in such a way that the product of the Y-axis reduction produced by each is the overall reduction required, and the error (ellipse)

produced by one link is cancelled by the error of the other. (By 'ellipsograph' is meant the type in which the motion of a straight rod is so constrained that one end travels along the X-axis, the other end along the Y-axis and any other point on the rod therefore describes an ellipse.) The result is obviously a straight line of the correct reduced length on the Y-axis. The above can only be true for a limited range of motion, which in the instrument shown has been arbitrarily set at $\pm 12^\circ$ relative to the horizontal axis. This angle together with a link length $AB = CD = 24$ in., gives adequate coverage for $8\frac{1}{2}$ in. $\times$ 11 in. paper.

Referring once more to Fig. 1, F and G are fixed guides which are clamped to the front edge of a drafting table. The instrument automatically aligns the guides, and the spacing between F and G may be adjusted to suit the chart being traced. F and

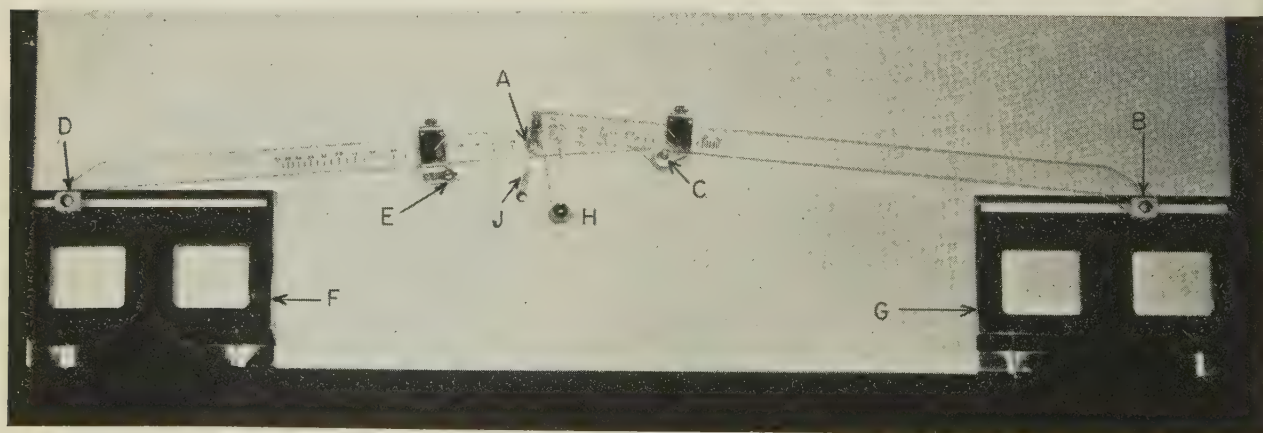


Fig. 1. Pantograph.

are so constructed that a long strip chart may be slipped underneath them, thus eliminating the need for cutting the chart.

On link AB, A is the stylus or tracer point, and B can both slide and turn in guide G, on a Teflon bearing.

On link CD, C is attached by a pivot to link AB by means of an adjustable clamp which may be set at any point on the B scale. D can both slide and pivot in guide F, on a Teflon bearing.

E is the pencil and is mounted in a clamp which can be set at any desired point on the CD scale. H is the operating knob (rigidly attached to AB), and J is an extra link which is only used when drawing ellipses. It constrains A to trace out a circle and in normal operation is not required. In order to reduce a graph along the Y-axis it is thus only necessary to set points C and E at the desired ratio (each scale at 2.0 is the setting in Fig. 1) and trace over the line with point A. The reduced graph will then be drawn by the pencil at point E. If an enlargement is required instead of a reduction, provision has been made so that the pencil and stylus may be interchanged.

The design of the instrument presented an interesting problem in scale calculation which was solved in the following manner:

Referring to Fig. 2, the two links are the same length, L . This is also true of the finished instrument where $AB = CD$ (Fig. 1.) The distance a locates the pencil and b locates the pivot attachment of the two links. Since the product of the reductions produced by the two links must be the overall reduction required, then:

$$\frac{a}{L} \times \frac{b}{L} = \frac{1}{n} \quad (1)$$

where n is the desired overall reduction.

The second requirement is that the error produced by the left link must cancel that produced by the right and so:

$$-a \left[1 - \cos \left\{ \sin^{-1} \left(\frac{b \sin \theta}{L} \right) \right\} \right] = (L - b)(1 - \cos \theta), \quad (2)$$

where θ has been arbitrarily chosen as 12° .

Since Eqn (2) is unusable in the form shown (except for a digital computer), series approximations were used to give the form:

$$1 - \frac{a}{L} = \frac{1 - b/L}{b^2 (\cos^2 \theta/2)/L^2} \quad (3)$$

It was then possible to use Eqns (1) and (3) as a simultaneous pair and solve for a and b .

It was realized that the series approximations had introduced an unknown error into the calculations, so numerous checks were made, substituting the values obtained from Eqns (1) and (3) back into Eqn (2). The maximum error was found to be 0.00116 in. The foregoing applies to X-axis error only. The instrument has no Y-axis error.

Canadian Patents and Development Ltd. have applied for a patent on this instrument.

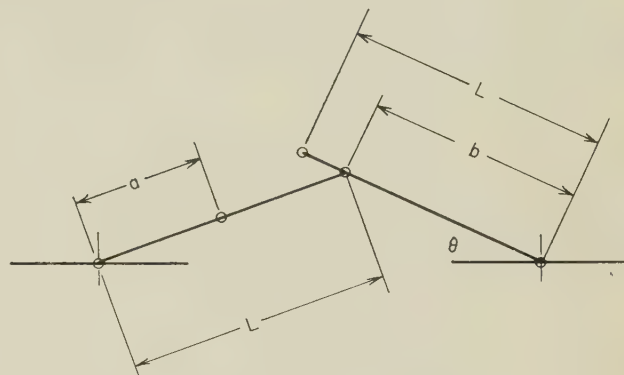


Fig. 2. Calculation of scale.

Acknowledgments

The author would like to express his thanks to Mr. E. L. R. Webb for valuable help in the basic design, to Mr. S. Tomkowicz for much of the detail design and to Mr. D. W. Johnston for his care in constructing the instrument.

A differential absorption spectrometer for the infra-red

by M. D. STURGE, Ph.D., Royal Radar Establishment, Malvern, Worcestershire

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Abstract

A method is described of measuring the small change in absorption coefficient due to the introduction of an impurity into a semiconductor. A chopped monochromatic beam of infra-red radiation is passed alternately through the doped and undoped halves of a compound specimen, and the resulting modulation measured. A change of less than 10^{-3} cm^{-1} can be observed in the presence of substantial background absorption. The method is illustrated by a measurement on oxygen-doped germanium.

Introduction

IN the course of a study of the infra-red properties at low temperatures of semiconductors doped with small quantities of impurity, the problem has arisen of measuring absorption coefficients due to the doping of the order of 10^{-2} cm^{-1} , in the presence of substantial background absorption and reflection loss. As it is difficult to measure infra-red transmission with an overall accuracy to better than 1%, a method of measuring directly the difference in absorption coefficient between a doped and an undoped sample has been developed. The method involves a straightforward modification of the system for making absorption measurements in semiconductors over a wide range of wavelength and temperature which has been used for a number of years in this laboratory (Macfarlane *et al.* 1957, Johnson 1959). In this system chopped monochromatic infra-red radiation is passed through a polished block of semiconductor, which is mounted in a low temperature cell. The transmitted radiation is focused on a detector, whose output is amplified and recorded. Readings are taken with the specimen successively in and out of the beam. The system is modified for differential measurements by making the specimen in two halves, which differ only in impurity content. The beam is passed alternately through the two halves with a repetition frequency of 1 c/s. The output of the detector then consists of a signal at the chopping frequency (10 c/s) proportional to the mean transmission of the compound specimen, which is modulated by a 1 c/s signal proportional to the difference in transmission between the two halves. After rectification of the 10 c/s signal, the 1 c/s is amplified and rectified. Small differences in transmission can be measured to an accuracy of less than 0.1% of the total by this means.

Experimental details

The specimen consists of two equal pieces of semiconducting material about $12 \text{ mm} \times 12 \text{ mm} \times 2 \text{ mm}$, one doped and the other undoped, but otherwise as nearly as possible identical. The large faces are cemented together with araldite, and the compound specimen is trued up, polished and mounted in the absorption cell in the same way as a conventional specimen (Roberts 1955, Macfarlane *et al.* 1957).

A schematic diagram of the apparatus is shown in Fig. 1. The Nernst filament source N and Golay cell G are standard equipment. The Leiss double monochromator L and the low temperature absorption cell A have been described by Roberts (1952, 1955, 1959) and no attempt is made to show their detailed design, which is unaltered. The radiation is chopped at 10 c/s by the ten-bladed chopper C, and can be cut off by the shutter T. A Pfund mirror system (Pfund 1927) is used to focus the radiation on to the Golay cell. The specimen S is mounted in such a way that the radiation beam can be switched from the doped to the undoped half by turning the mirror M through 2° about a vertical axis.

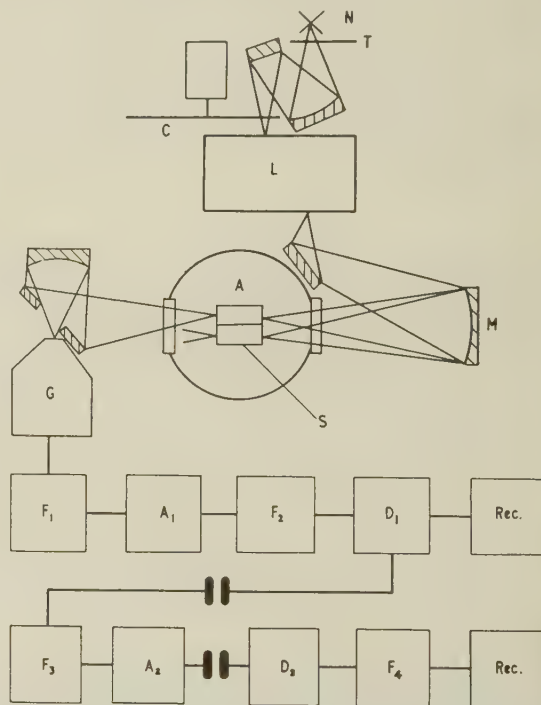


Fig. 1. Schematic diagram of the differential absorption spectrometer.

This mirror (which images the exit slit of the monochromator on the specimen) is mounted on the armature of a relay (Siemens type 100), which is driven at 1 c/s from a commutator on the shaft of the chopper. An oscillating mirror is simpler mechanically than other methods of obtaining two beams separated in space, such as the chopper type of beam splitter used in most commercial double-beam spectrometers. The method has the great advantage that the two beams are only separated by a few millimetres at the specimen, and traverse almost the same optical path.* The

* An oscillating mirror has been used in a double-beam infra-red microscope by Haggis (1956), who, however, measured the ratio of the intensities of the two beams, rather than their difference.

recombined simply by imaging M on the absorbing membrane of the Golay cell.

In the output of the Golay cell there is, in addition to the desired 10 c/s signal modulated at 1 c/s, a 1 c/s signal (not modulation) due to room temperature radiation from the surroundings of the monochromator exit slit, which the cell 'sees' in the oscillating mirror. For this reason, the infra-red radiation is chopped before entering the monochromator. The 1 c/s fundamental of this spurious signal is removed by the parallel-T filter F_1 , and higher components are reduced as far as possible by blackening the slit jaws with an aquadag-waterglass mixture (adapted from the formula of Kubens and Hoffman (1922)). Under these conditions modulation of the 10 c/s signal by the spurious signal, due to non-linearity of the Golay cell and the 10 c/s amplifier, has been found to be small. The 10 c/s signal is amplified by the broad band amplifier A_1 , 50 c/s hum is removed by the filter F_2 , and the signal is rectified by the phase-sensitive detector D_1 , which is an Elliott mercury-wetted relay operated by the chopper. The d.c. level here, which represents the mean 10 c/s signal and is proportional to the average transmission of the two halves of the specimen, is smoothed and recorded. The 1 c/s signal is filtered by F_3 to remove higher frequency components and is amplified by the stabilized d.c. amplifier A_2 , which has capacitive input and output coupling and whose gain is accurately controllable in steps from 1 to 100 (the gain is checked in each run). The phase sensitive detector D_2 , filtering and integrating circuits F_4 (with a time constant of 10 seconds) follow. The d.c. output is proportional to the difference of transmission of the two halves of the specimen, and is recorded.

At each wavelength, measurements are made under four conditions: (1) specimen out, radiation off; (2) specimen out, radiation on; (3) specimen in, radiation off; (4) specimen in, radiation on. The 1 c/s detector is short-circuited for six seconds between each reading to allow transients to decay. The entire sequence of readings is carried out automatically (Johnson 1959). Representing the d.c. output of the 10 c/s detector by A and that of the 1 c/s detector by B we have:

$$T_{\pm} = \frac{2G\{A(4) - A(3)\} \pm \{B(4) - B(3)\}}{2G\{A(2) - A(1)\} \pm \{B(2) - B(1)\}}$$

where T_+ and T_- are the transmissions of the undoped and doped halves of the specimen respectively, and G is the gain of the 1 c/s amplifier and its associated circuits. The absorption coefficient α is related to T by the equation (Fan 1956)

$$T = \frac{(1 - R)^2 \exp(-\alpha t)}{1 - R^2 \exp(-2\alpha t)}$$

where R is the reflection coefficient (found from T in a region of low absorption) and t is the thickness of the specimen. T_+ , T_- , α_+ , α_- and $\alpha_- - \alpha_+$ are calculated from the data in the laboratory's electronic computer.

Relative photoconductive response can be measured simultaneously with the absorption measurement. Leads are soldered to the doped half of the specimen, and the 10 c/s photoconductive signal P measured in the conventional manner. The relative response is given by

$$\{P(4) - P(3)\} / \{A(2) - A(1)\},$$

the variation with wavelength of atmospheric absorption and window loss is neglected.

Performance

In principle the sensitivity of the differential system is limited by detector noise. As G , the gain of the 1 c/s amplifier, is increased, it is convenient to reduce the gain of the 10 c/s amplifier to keep the noise in the 1 c/s output constant. Then at a given wavelength, the minimum detectable change in absorption coefficient $\delta\alpha$ is related to the spectral slit width $\delta\nu$ and to G by $\delta\alpha \propto \delta\nu^{-2} \propto G^{-1}$. In practice $\delta\alpha$ is about 50% greater than it should be due to detector noise alone, as some scatter is introduced by the effects of room temperature radiation mentioned above. However, in conventional absorption measurements (Macfarlane *et al.* 1957, Johnson 1959) there are several sources of systematic error which combine to produce an uncertainty in the measured transmission ratio of the order of 1%. These are, typically, drifts in the source intensity, amplifier gain, and atmospheric absorption, non-linearity of the amplifier and detector, and (when the intrinsic absorption is varying rapidly with wavelength) errors in the wavelength calibration. These errors are still present, of course, in the differential method, but appear as a percentage of the difference in transmission, rather than of the total, and are usually small compared with random error. This gain in sensitivity is illustrated in Fig. 2, in which the differential

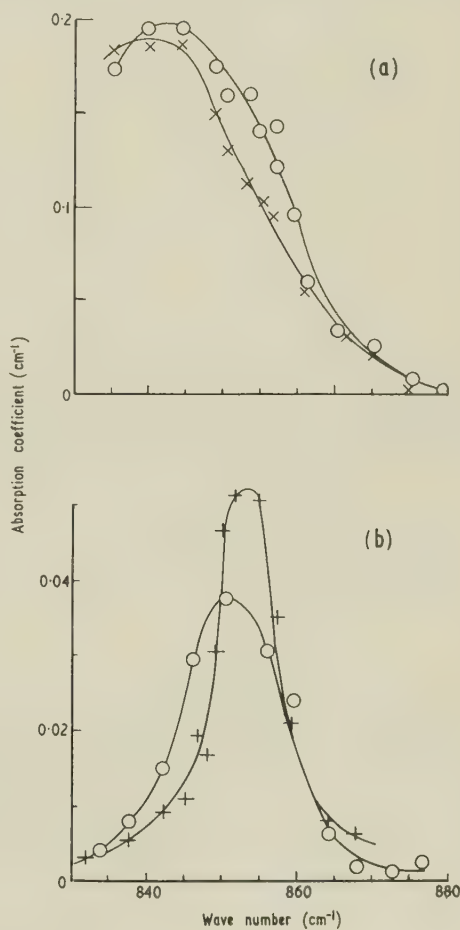


Fig. 2. The 11.7 μ oxygen line in germanium: (a) 'straight' absorption at 290° K. O, oxygen-doped Ge. X, oxygen-free Ge; (b) differential absorption at two temperatures, $G = 20$: O 290° K, + 21° K.

method is compared with the conventional 'straight' method in a measurement on the 11.7μ line due to oxygen in germanium (Kaiser, Keck and Lange 1956). Fig. 2(a) shows the results of measurements with a conventional prism spectrometer (resolution 8 cm^{-1}) on 1 cm thick slices of oxygen-doped and oxygen-free germanium. The oxygen line is just observable as a bump on the side of a lattice band. Fig. 2(b) shows, on an expanded vertical scale, the same line, measured with the same resolution by the differential method. The shape and position of the line, and the effect of temperature, can be accurately determined (more precise measurements on this line, over a wide range of temperatures, will be published elsewhere). The results at room temperature agree well with those of other workers (Kaiser, Keck and Lange 1956, Bloem, Haas and Penning 1959) using conventional techniques on more heavily doped samples. The results at 21°K , where the natural line width is small, have been verified directly with a conventional grating spectrometer. Under high resolution (0.7 cm^{-1}) the peak absorption becomes large enough for the conventional method to be quite accurate, and the integrated absorption (which should be independent of slit width) agrees closely with that found by the differential method. Differences of absorption coefficient are reproducible to less than $\pm 0.002\text{ cm}^{-1}$ under the conditions of Fig. 2. Smaller changes in absorption coefficient can be measured, at the expense of resolution, by increasing G .

Acknowledgments

It is a pleasure to thank my colleagues for their assistance in particular Mr. J. F. C. Oliver for much of the detailed design and constructional work, and Dr. F. A. Johnson and Mr. J. E. Quarrington for helpful discussions.

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Analogue method for computing the number of spins contributing to a magnetic resonance absorption

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MS. received 10th October 1960

Abstract

An analogue method is described by which the number of spins contributing to a magnetic resonance absorption line may be computed from a recorder tracing of the derivative of the line. Since the area under an absorption profile is proportional to the first moment of the algebraic area under its derivative, it may be determined by a simple balance and cardboard cut-outs of the tracing.

ELECTRON spin resonance spectrometers, used for example in the investigation of free radicals, usually employ magnetic field modulation and phase-sensitive detection. In this type of instrument the results are normally

plotted by a pen recorder in terms of the derivative of the power P absorbed by the sample, as the precession field H is swept linearly. A typical recorder tracing is shown in Fig. 1(a). The number of electron spins contributing to the absorption line is proportional to the area under the absorption profile (Fig. 1(b)).

One method which has been proposed (Ingram 1958) for determining this area involves the construction of the absorption profile by integration of the recorder tracing. Further integration is then necessary to obtain the required area. A simpler procedure can be based on the fact that the area under the absorption profile is equal to the first moment about any vertical axis $H = H_x$ of the algebraic area enclosed

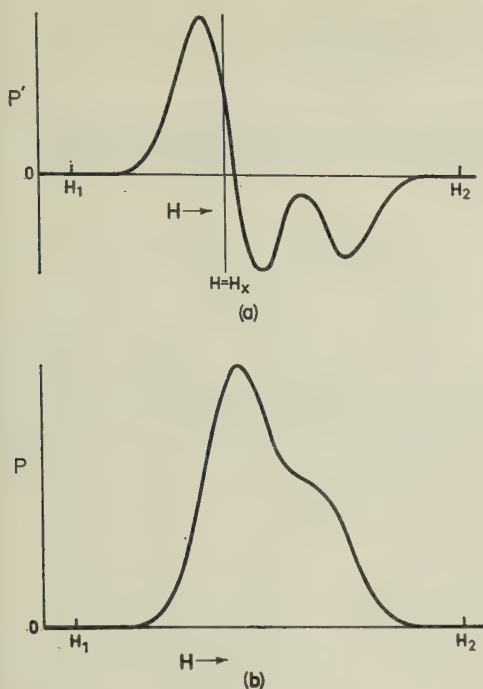


Fig. 1. (a) A typical derivative tracing from an electron spin resonance spectrometer, (b) The actual absorption profile obtained by integration of (a).

between the derivative curve P' , and the line $P' = 0$. This can be shown as follows. Let H_1 and H_2 lie to either side of the absorption line, as in Fig. 1. Then the area under the absorption profile is

$$\begin{aligned} \int_{H_1}^{H_2} P dH &= \left[PH \right]_{H_1}^{H_2} - \int_{H_1}^{H_2} HP' dH \quad (\text{by parts}) \\ &= - \int_{H_1}^{H_2} HP' dH \quad (\text{since } P = 0 \text{ at } H_1 \text{ and } H_2) \\ &= \int_{H_1}^{H_2} (H_x - H) P' dH - H_x \int_{H_1}^{H_2} P' dH \\ &= \int_{H_1}^{H_2} (H_x - H) P' dH \quad (\text{since } P = 0 \text{ at } H_1 \text{ and } H_2), \end{aligned}$$

thus is the moment about $H = H_x$. The moment can be evaluated by a single numerical integration, but in many cases an analogue method may be an attractive proposition. If the curve from the recorder is traced on to cardboard, the areas between the P' curve

and the line $P' = 0$ can be cut out and the moment about $H = H_x$ found by means of a simple balance. The axis $H = H_x$ is placed along the fulcrum and the areas which lie below the line $P' = 0$ are reflected across the fulcrum to give them the effect of negative weight, as illustrated in Fig. 2. The axis $H = H_x$ is usually drawn in the position shown in Fig. 2, but it can be located at any value of H .

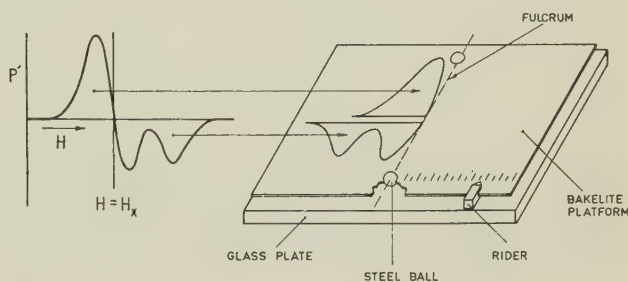


Fig. 2. Sketch of the balance, showing the moment of a typical tracing being determined by means of cardboard cut-outs.

The design of the balance is not critical, and it does not need a wide range of sensitivity, since the gain and chart speed of the spectrometer are usually adjustable to give curves of similar size on the chart. A balance constructed as illustrated in Fig. 2 has been found very satisfactory. The platform on which the cardboard is placed consists of a 5 in. square of $\frac{1}{32}$ in. Bakelite sheet. Two $\frac{3}{8}$ in. diameter steel balls cemented into holes in the platform allow it to rock on a glass plate with very little friction. The centres of the balls are located slightly above the platform to ensure stability. The system is balanced by means of a rider of about 1 g weight, the reproducibility of the balance point being better than 1% of full scale.

To obtain an absolute determination of the number of spins, the response for each sample is compared with that from a small weighed quantity of a standard substance, such as copper sulphate pentahydrate, for which the number of spins can be calculated.

This analogue method is, of course, also applicable to the analysis of nuclear magnetic resonance recordings where phase-sensitive detection is employed.

Acknowledgment

The author wishes to acknowledge helpful discussions with Dr. G. S. Bogle.

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Servo-operated respiratory waveform simulator

by D. W. HILL, M.Sc., A.Inst.P., A.M.I.E.E., and J. R. HOOK, A.I.B.S.T., Research Department of Anaesthetics, Royal College of Surgeons of England, London, W.C.2, and E. G. BELL, A.M.I.E.E., Servomex Controls Ltd., Crowborough, Sussex

MS. received 5th October 1960

Abstract

An apparatus for the generation of typical respiratory patterns is described. Two pistons are driven by a half horse-power servomotor operated by a Velodyne speed control system. The desired waveform is produced by means of a cam or photoelectric function generator.

IN laboratories concerned with the design and development of breathing equipment and anaesthetic apparatus there is a need for a versatile device for the generation of typical respiratory waveforms. This device can then replace a human subject in an anaesthetic or breathing apparatus circuit, and experiments can be continued for long periods of time if necessary or, alternatively, experiments can be repeated under reproducible conditions at some later date. Experiments which require a respiratory simulator include the measurement of the resistance to breathing of breathing apparatus components, the calibration of flow rate and volume recorders and the testing of soda lime canisters for carbon dioxide absorption.

In most laboratories some form of ventilator is pressed into service as a respiratory simulator. Although ventilators have the advantage of being commercially available in various forms, they usually generate a mirror image of the respiratory waveform required as they are designed for the automatic inflation of a patient's lungs. In addition, the choice of waveforms available is often somewhat restricted. Ventilators operated from a source of compressed gas are better in this respect, but for routine laboratory use a mains-operated electrical system is preferred.

On the grounds of greater reproducibility, a piston and cylinder arrangement was preferred to a bellows system. The use of a moving piston and linkage limits the attainment of the highest rates of acceleration from consideration of moments of inertia. When extremely rapid inspirations and expirations have to be generated, then a pneumatic system, utilizing a source of suction to generate the inspiration and a source of pressure to generate the expiration, might well be the only system capable of producing the required results. The simulator was developed mainly for the testing of anaesthetic apparatus, and with anaesthetized patients the breathing patterns are naturally quieter than with subjects undergoing extremes of exercise.

The motion of the piston may be controlled in several ways, for example, by spring-loading the piston on to a suitably shaped cam revolving at the desired respiratory rate or by actuating the piston linkage from a constant-speed motor via a variable-speed gear-box. The ratio of the gear-box is varied by a cam to give the desired breathing pattern. After considering such systems, a respiratory simulator was finally designed around a Velodyne variable-speed motor control circuit (Uttley and Williams 1946, Dickinson 1950). Such

a system is attractive because it offers a wide range of smooth speed control and the motor speed is set by the application of a control voltage to the system. This fact encourages the use of a low-frequency function generator to generate electrically the respiratory waveform.

In order to achieve sufficiently rapid accelerations a half horse-power split field d.c. servo-motor (Servomex type MC47) is employed. The motor armature supply is derived directly from the a.c. mains via a series capacitor, bridge connected metal rectifier and smoothing choke. This combination provides a sensibly constant armature current of some three amperes. Thus the motor will not overheat when running at low speeds and will remain stationary when equal and opposite currents of 40 mA d.c. flow in each half of the field winding.

The motor field windings are connected to a conventional servo-amplifier, which may be as described by Dickinson (1950) or a commercial amplifier. With the input to the amplifier earthed by switch S_2 (Fig. 1) the amplifier balance

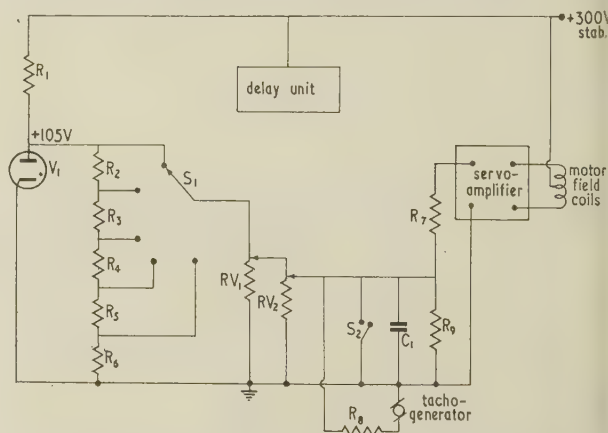


Fig. 1. Circuit diagram of Velodyne speed control.

$R_1 = 10 \text{ k}\Omega$, 5 W
 $R_2 - R_6 = 10 \text{ k}\Omega$, 1 W
 $R_7 = 100 \text{ k}\Omega$, $\frac{1}{2}$ W
 $R_8 = 47 \text{ k}\Omega$, $\frac{1}{2}$ W
 $R_9 = 1 \text{ M}\Omega$, $\frac{1}{2}$ W
 $C_1 = 1000 \text{ pF}$, 350 V
 $RV_1 = 100 \text{ k}\Omega$, linear
 $RV_2 = 50 \text{ k}\Omega$, log

control is adjusted until the motor stops and the input then connected back to the speed control circuit. By means of the coarse- and fine-speed controls a positive voltage is tapped off from the type OB2 stabilizer tube and applied to the input of the amplifier. This causes the amplifier to unbalance, the current in one field winding increasing to 80 mA and in the other falling to zero. Under these conditions the motor rapidly accelerates and the voltage output of the coupled d.c. tachogenerator correspondingly increases.

The voltage output of the tachogenerator is arranged to be of a negative polarity and is also applied to the input of the servo-amplifier, as shown in Fig. 1. When the generated negative voltage is equal and opposite to the applied positive voltage, the amplifier is again balanced and the motor slows down. Thus the motor settles at a speed level determined by the value of the voltage applied from the speed control network.

In practice three speed controls are used. Resistors R_2 to R_4 provide a switched coarse speed control and potentiometer RV_1 a fine control. Logarithmic potentiometer RV_2 is spring-loaded and actuated from the respiratory-pattern control cam via a follower and Bowden cable. A suitably engraved disk can replace the cam and, together with a light source and photocell arrangement, can generate the pattern, thus eliminating wear on the potentiometer and disk. The cam or disk is mounted on the master camshaft described later on.

contacts do not stay closed since this would upset the operation of the delay circuit. This is quite conventional, being based on a pair of cathode-coupled pentodes, one of which is normally conducting and the other cut-off. For the duration of the delay the state of the valves is reversed. The total delay available is four seconds.

The servo-motor is connected to the piston linkage via a worm gear giving a speed reduction of 25 : 1. The output from this gear is connected by a chain and sprockets to the master camshaft and by a connecting rod to a pair of rocking beams. The linkage connecting the pair of pistons to the beams has been designed to enable the stroke volume of either of the pistons to be continuously adjustable whilst they are in motion, and also to allow the pistons to be either in phase or 180° out of phase with each other. This is achieved by using a pair of differential gears, one of which is shown in Fig. 2. The differential gear forms the basis of the mechanism and has 8 mm roller chain sprockets (3) and (4)

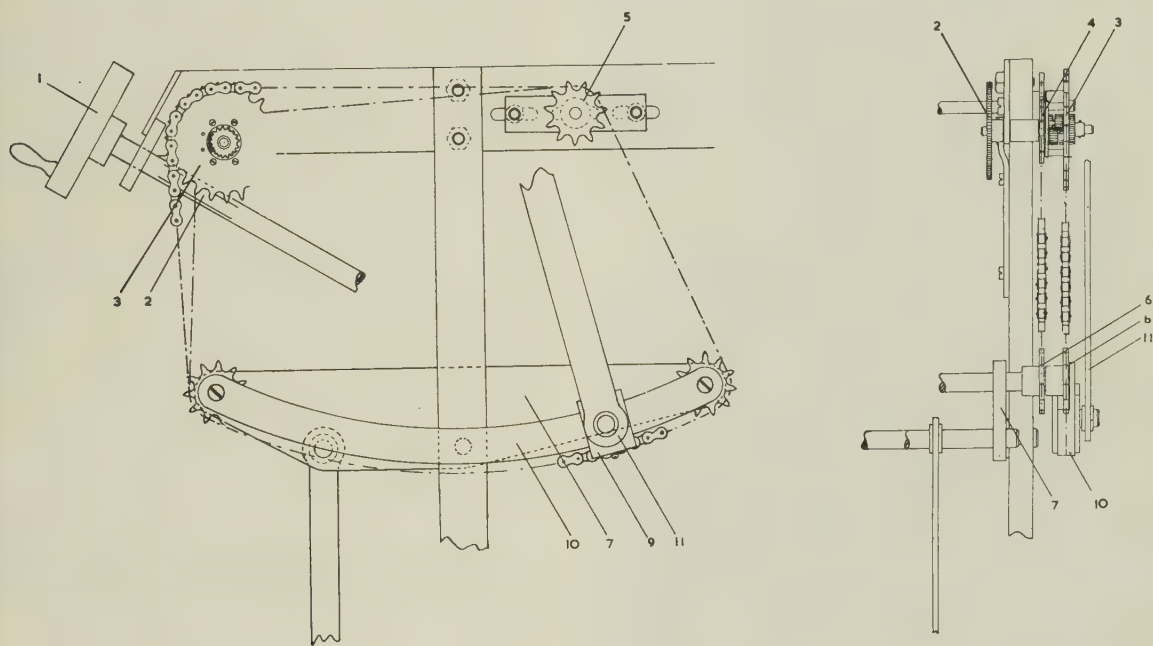


Fig. 2. Piston linkage.

A switch is provided to cut out the cam-operated speed control, in which case the pistons follow a cycle which is a sine wave, as determined on a high-speed recorder, with a maximum respiratory rate of 160 breaths per minute. Under these conditions a voltmeter connected across the output of the tachogenerator is calibrated in breaths per minute. The sine waveform is used in the testing of anaesthetic vaporizers. In some breathing patterns there may be a significant pause occurring after the end of each expiration. This post-expiratory pause is conveniently generated by means of a delay circuit. At top dead centre a microswitch is closed, which means of a cam mounted on the camshaft, and feeds the 0 v h.t. line to a high-speed relay via a series capacitor and resistor. The high-speed relay then closes momentarily and starts the delay circuit operating. The action of the delay circuit is to connect the input of the servo-amplifier to earth for the duration of the delay; the microswitch contacts, in fact, stay closed throughout the delay period. The capacitor feed to the relay ensures that the initiating

mounted on it. The other differential gear is driven by a hand wheel (1) via a worm and wheel (2) from the control panel. The sprocket on the cage (3) is twice the diameter of the other sprocket (4). It can be seen that, through the differential action, by pulling one of the chains an equal amount will be fed out of the other (the cage going at half the speed but with twice the number of teeth). Both chains run over spring-loaded jockey sprockets (5) at the back of the apparatus. One chain is attached to a pair of fixed sprockets (6) at each end of a rocking beam (7), whilst the other forms a continuous loop running over a pair of free sprockets (8) on a common axis with the fixed ones. Attached to the loop is a block (9) which slides on the radiused guide (10), which also forms the bottom bearing for the piston connecting rod (11). Whilst the beam is being driven from the motor, this block remains stationary. However, if the hand wheel on the front panel is operated, the anchored chain cannot move. Therefore, the looped one has to move, taking with it the bearing block and thus changing the stroke

volume. If the block passes the mid-position it also reverses the phasing. This mechanism is duplicated on the other side to operate the second piston.

The pistons and cylinders are turned from Perspex in order to allow the stroke pattern to be seen and to keep the weight down. No trouble has been experienced with overheating or warping of this material. Contra-pistons are fitted to each cylinder and these enable the residual volume above top dead centre to be varied. The maximum stroke

volume of each piston alone is 1.4 litres. The pistons are sealed with Perspex rings as in an internal combustion engine and castor oil or other suitable lubrication is employed. This construction reduces vibration to a minimum, since this effect can spoil recordings of the flow-rate pattern. Instantaneous flow rates and tidal volumes are recorded by means of an integrating pneumotachograph (Hill 1959) and a Sanborn pen recorder. The shape of the pattern can be derived from pneumotachograph tracings obtained from human subjects. The master camshaft carries a further cam to actuate a solenoid-operated inspiratory-expiratory valve (Hill and Hook 1958) if this is required. A general view of the simulator is shown in Fig. 3.

The use of two separate pistons and cylinders allows the simulation of the different inspired and expired gas volumes encountered in the altitude testing of aircrew breathing equipment, and also of inspired and expired gas mixtures of different composition. If the temperature and humidity of these mixtures has to be held constant, then lagged metal cylinders would be used.

In Fig. 4 are shown tracings obtained with the respiratory simulator taking the place of a pilot in the testing of an oxygen demand regulator. A pneumotachograph head and Satham strain gauge records the flow-rate pattern, and the oxygen mask tube pressure and oxygen mask cavity pressure are also measured with Satham strain gauges. The pressure



Fig. 4. Tracing from the testing of an oxygen demand regulator using the respiratory simulator.

were recorded on a three-channel high-speed photoelectric galvanometer recorder. The simulator delay was set to give a two-second pause between successive breaths, and the peak flow rate was 120 l./min.

Acknowledgments

It is a pleasure to acknowledge the encouragement of Professor Ronald Woolmer, Royal College of Surgeons, for this work and the Directors of Servomex Controls Ltd. for giving permission to publish. The Mechanical Engineering Division of the Royal Aircraft Establishment kindly offered valuable advice and provided Fig. 4.

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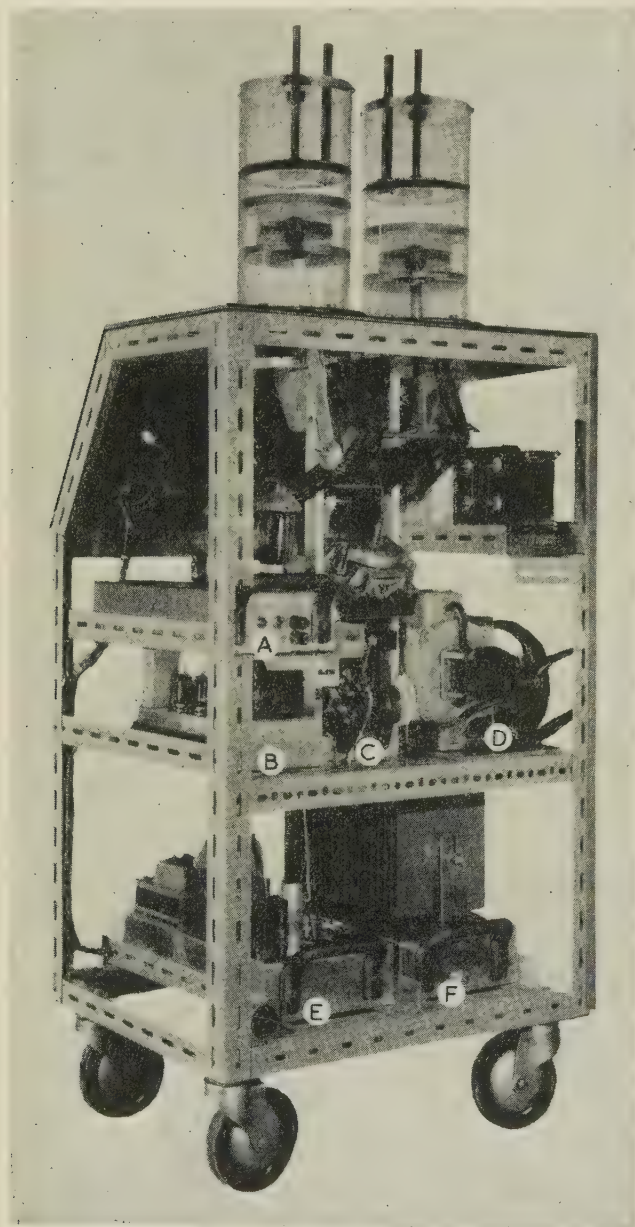


Fig. 3. Respiratory waveform simulator.

A, servo-amplifier; B, delay unit; C, master camshaft; D, servo-motor; E, h.t. power supply; F, armature power supply.

Outgassing of large vacuum-systems to a temperature of 450° C

by A. L. BOERS and J. B. VAN DIËN, Fysisch Laboratorium, der Rijksuniversiteit te Utrecht, Holland

MS. received 16th September 1960, in revised form 10th November 1960

In many laboratories it has been found necessary to heat metal vacuum systems repeatedly or permanently to a temperature of more than 300° C in order to outgas the walls efficiently. For large vacuum systems it is difficult to use means surrounding the system entirely. Consequently the heating is restricted to parts of the system by means of local heating elements. At places which cannot be heated directly, loss of heat is avoided by insulating as much as possible. We used the system of local electric heating employing Kanthal tape, electrically insulated with Micanite, as a resistance heater. Asbestos was chosen for external heat insulation.

Resistor tape was preferred to wire because: (i) the heat-contact with the surface to be heated is larger; (ii) it is easier to wind crosswise.

As electric insulating material we also tested ceramic tiles, which unfortunately gave a bad thermal contact, and glass-tape, in which electric breakdowns occurred frequently at temperatures of about 200° C.

For straight parts of tubes in the system to be outgassed were surrounded by a double layer of Micanite (thickness about 2 mm). In order to obtain a good mechanical contact with the surface of the tube, the Micanite was first pressed in by means of a close winding of rope; this was wound gradually as the Kanthal tape was wound into position. When the magnetic field caused by a single layer of heater-windings was troublesome, a crosswise winding was applied in two layers in which the currents ran in opposite directions so that the magnetic fields compensated each other. The two layers were connected in parallel, so that there were no potential differences between windings at cross-over points. The tape used in this case had a cross section of 0.1 mm × 1 mm and a resistance of 14 ohm/m. The pitch of the windings was 5 mm; this allowed reliable winding without short-circuiting, at least at tube diameters of 2–8 cm. At a greater pitch the current has to be higher to achieve the required heat production, and this results in greater differences in temperature. At a smaller pitch the angle at which the tapes cross each other becomes small, thus causing considerable overlap where very little heat could be produced.

When the magnetic field was not troublesome, a single winding was applied with a tape of 0.1 mm × 2 mm, again with a pitch of 5 mm. At the same current the power per unit surface area was the same in each case, namely $4 i^2$ W/cm² (with i in amps).

Heating elements were also fitted around the flanges of vessels, so as to prevent undue loss of heat. The flange heaters were short cylinders containing a zigzag winding of Kanthal tape, 0.1 mm × 2 mm, mounted on a strip of Micanite and shielded by layers of Micanite and tinplate. The elements were covered by two layers of asbestos (thickness 4 mm) which were fastened with a brass tape (see Fig. 1). In this way it was possible to heat the couplings to the same temperature as the straight tubes.

The temperature of the heated tube or flange was measured

with a thermocouple (Philips type R7 990 40). The brazed joint of the couple was insulated with two strips of mica and placed between the heating element and the tube or the flange.

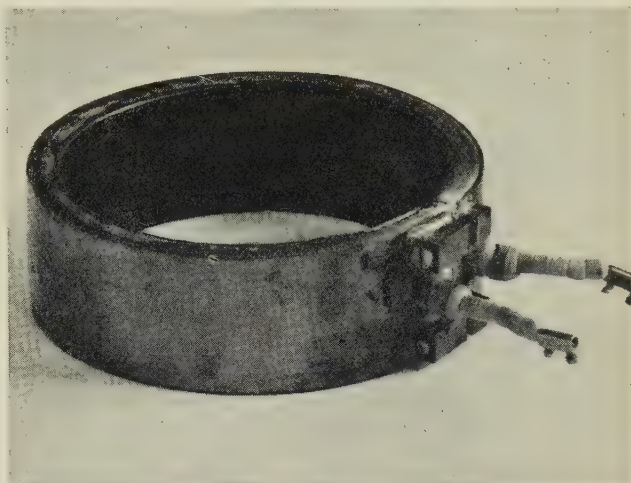


Fig. 1. Heating element for pairs of flanges.

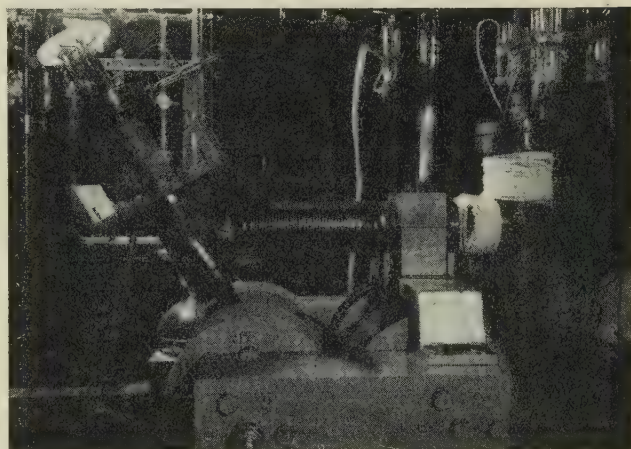


Fig. 2. Mass spectrometer with heating elements.

When the above method of outgassing was applied, a temperature rise to above 450° C could be attained with a current of about 3 A (about 1.25 W/cm²). A potential difference of 220 V a.c. between the heating tape and the tube did not cause electrical failure after one year of operation.

One of the first applications was the outgassing of an all-metal mass spectrometer (see Fig. 2). The mass spectrometer was pumped with an Edwards F 203 diffusion pump, with baffle-valve and liquid air trap giving a speed of about 25 l/s at the receiver. The pump fluid was 'Apiezon' C. The vacuum seals were flat flanges with copper O-rings, 1 mm diameter. The liquid air trap was filled immediately after the heating process. The surface area of the metal system to be baked out was 4100 cm². A limiting pressure of 10⁻⁸ mm Hg could be obtained. Fig. 3 shows mass spectra of the residual gas before and after outgassing. The

intensity values given in the graph are proportional to the ion-current readings.

This work is part of the research programme of the

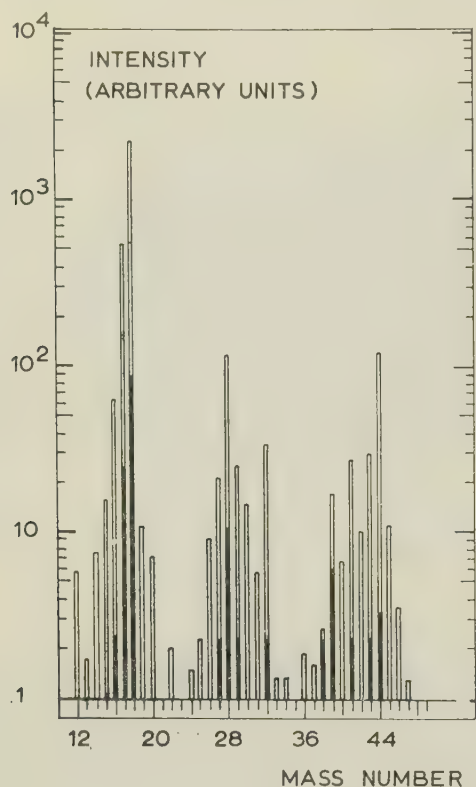


Fig. 3. Mass spectra of the residual gas.

□ before outgassing,
■ after outgassing.

The pressures were respectively 4×10^{-7} and 2×10^{-8} mm Hg; the emitter material was tungsten.

Stichting voor Fundamenteel Onderzoek der Materie, and was made possible by financial support from the Nederlandse Organisatie voor Zuiver Wetenschappelijk Onderzoek.

A simple method of monitoring the rate of deposition of a conducting film in a vacuum chamber

by K. FELDMESSER, 16 St. Vincent Drive, St. Albans, Hertfordshire

MS. received 8th November 1960

If a monitoring resistance element in a chamber of a vacuum metallizing plant is connected to a Wheatstone bridge set to the desired final value, the bridge will be grossly unbalanced before and during the initial stages of deposition and the galvanometer will pass rapidly through the balance condition without warning. If the process of deposition is monitored by 'following' the resistance values on the bridge, evaporation has to be slowed up and the desired end-point can easily be missed.

A method which improves on these without great complication whilst maintaining the accuracy of a bridge consists in replacing the bridge galvanometer by a microammeter shunted by a thermistor bead (such as the Standard Tele-

phones and Cables type E 2361/20) together with a variable series resistor to adjust the full-scale sensitivity. The desired final resistance value is then pre-set on the bridge with the monitoring element connected and the series resistor adjusted for full-scale deflection. As evaporation commences the meter needle will fall from full scale indicating the rate of deposition on something like a logarithmic scale. As the bridge approaches balance and the out-of-balance current falls, the thermistor bead approaches its maximum resistance value and nearly the full meter sensitivity is available for monitoring the end-point.

The method has been found simple and inexpensive, giving the accuracy of a bridge with the convenience of an ohmmeter.

The author gratefully acknowledges the permission of Messrs. Marconi Instruments Ltd. to publish this note.

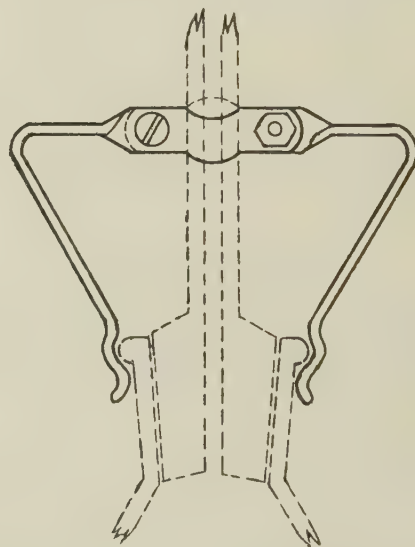
A clip for the rapid attachment of Warburg flasks

by R. J. ROMANI, Department of Pomology, University of California, Davis, California

MS. received 21st November 1960

The present method of securing Warburg flasks to manometers requires the attachment of two small springs on equally small and elusive glass hooks, a procedure that is inconvenient and time consuming. A clip patterned after the full-scale sketch shown below accommodates all flasks which have a raised rim and greatly expedites their attachment to manometers, obviating the use of springs and hooks.

Each leg of the clip is fashioned from separate strips of stainless steel, spring copper or other resilient, non-rusting



The clip shown attached to a manometer stem and clamping the edges of a Warburg flask.

metal and secured to the manometer stem with two small bolts. The height of the clip should be so adjusted that its maximum upward thrust is exerted at the rim of the flask. By simply pushing the flask into place and rotating slightly to distribute a thin layer of grease, a very rapid and satisfactory attachment is achieved. A slight downward pressure quickly removes the flask.

Verification of low loads in hardness testing machines

by R. J. ELLIS, Division of Metrology, National Standards Laboratory, C.S.I.R.O., University Grounds, City Road, Chippendale, N.S.W., Australia

MS. received 16th November 1960

though it is not general practice in macro-hardness testing to use an indenter load as low as 1 kg, there is provision for in some standard specifications to meet particular needs, and the load range of some widely used types of machine tends to this low value. Thus, there is a need for verification of this load.

The method adopted for measuring an indenter load should reproduce the actual conditions of test as closely as possible; the proving device should measure the load applied by the indenter when the machine is operated in the normal manner. An instrument developed for verifying the 1 kg load is illustrated in Fig. 1 which shows an equi-arm lever of arm

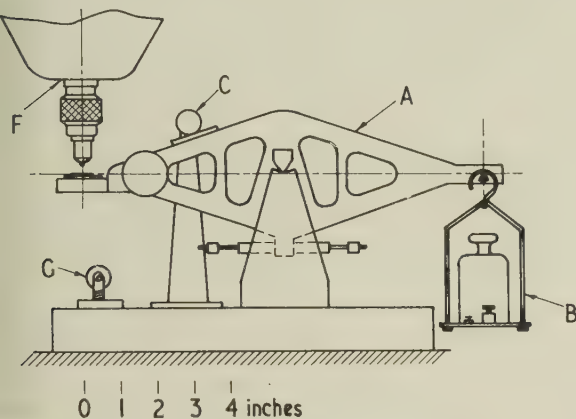


Fig. 1. Instrument in hardness testing machine.

A, lever; B, scale pan; C, mechanical stop; F, plunger of hardness machine fitted with ball indenter; G, indicating lamp.

length 5.5 inch set up on the work table of a hardness testing machine. The lever unit has been adapted from a device formerly used in the laboratory for the hardness testing of instrument pivots.

In use, the lever A with empty scale pan B is first adjusted to balance when just clear of the stop C, where a simple electrical contact is arranged to extinguish a lamp G when contact is broken. Weights slightly in excess of the load to be measured are placed on the scale pan, causing the lever to bear against C. The hard steel insert D (Fig. 2(a)) is temporarily removed. Adjustment is made to the height of the work table and the position of the instrument until, with a ball indenter engaged in a conical seat in E, the indenter plunger moves freely in its guide, under load. The

table is then lowered and the insert replaced. The table is now raised until the gap between the insert and the indenter is appropriate for a hardness test.

The machine is then operated in the normal manner. The ball indenter moves down until it meets D, and tends to force

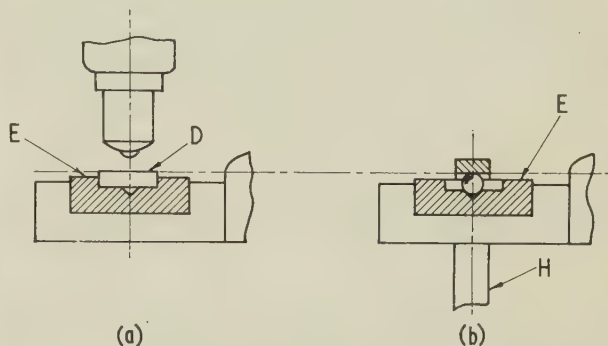


Fig. 2. (a) Alignment under indenter. (b) Calibration of instrument.

D, hard steel insert; E, mounting for D; H, weight hanger for calibration of lever.

the lever clear of C. The machine is operated a number of times, as the weights in the scale pan are progressively reduced, until the load applied by the indenter just breaks the contact at C as indicated by the lamp. The weight on the scale pan is noted.

The true indenter load is the product of the weight on the scale pan and the calibrated lever ratio (nom. 1:1), due allowance being made for any difference in weight between the ball indenter and the diamond pyramid indenter normally used. The lever ratio is determined using a weight carrier H supported on a 2 mm diameter steel ball which rests in the conical seat in E, as shown in Fig. 2(b).

Three possible sources of error, which could affect the lever ratio of the instrument in use, have been considered:

- (1) Variation in the path of the indenter in successive tests.
- (2) Misalignment of the conical seat under the indenter.
- (3) Change in the horizontal distance between the indenter and the main knife of the instrument lever during vertical adjustment to the work table.

Investigation has shown that the total error from these sources can be kept within 0.1%.

ACKNOWLEDGMENT

The author wishes to acknowledge the assistance of Mr. H. Simmons, a Technical Assistant in the Division of Metrology, in the determination of the accuracy of the method described.

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep her informed of their new or improved products. The Institute of Physics and The Physical Society assumes no responsibility for the statements given below; information for these has been taken from literature supplied.

Differential humidity indicator. Negretti and Zambra Ltd., London, W.1.

The instrument comprises an indicator and a pair of electrolytic elements. These elements each consist of a specially impregnated fabric which is carried on platinum-clad electrodes. The fabric has the property of rapidly attaining the moisture content of the surrounding atmosphere, and this governs the resistance value of the element. Each element is fed with an alternating current at constant voltage from the indicator and the resistance change with the humidity thus varies the current flow through it. The elements are installed at stations between which the humidity difference is required to be known; these may be at a considerable distance from the indicator. No artificial circulation of the air surrounding each element is required, normal convection currents being sufficient to allow the element to attain equilibrium conditions. The elements are of the plug-in type. The mains unit produces a stabilized alternating square wave form at constant voltage and this is fed to the elements to overcome the effects of polarization. The currents produced through the elements pass through the rectifier circuits and the galvanometer is connected so as to indicate the current difference. The galvanometer has a centre zero enabling both positive and negative humidity differentials to be indicated; the scale is calibrated $-35-0-35$ units, the units corresponding approximately to % relative humidity.

Electronic weighing system. Microcell Ltd., Camberley, Surrey.

This system is based on the design of a photoelectric transducer which can be attached to the existing weighing machine and translates movement of the weigh-beam into a train of digital pulses; the number of pulses produced is proportional to the weight applied to the machine. A series of counting circuits allows this digital train to be translated into a voltage which controls not only the rate of feed to the machine, but also stops feeding as soon as the contents weight has reached any predetermined quantity. This process can lead to systems where labels bearing tare and net weight are produced automatically as the products are weighed. At the same time the values may be recorded in a form suitable for feeding to existing punch card or punch tape accounting installations. The system has been designed to meet Board of Trade requirements of accuracy.

Direct-writing oscillograph recorder. Savage and Parsons Ltd., Otterspool, Watford, Hertfordshire.

This new direct-writing oscillograph is capable of recording at frequencies from d.c. to 1000 c/s and above. It provides a choice of eight paper speeds, from 5 inches a minute to 150 inches a second and is claimed to give a well defined trace at writing speeds in excess of 12000 inches per second. The recorder is designed as a 12-channel unit and the magnet block carries 15 pencil-type mirror galvanometers, the additional three channels serving for time or event marking or as extra recording channels if desired. By the operation of a switch, two of these three galvanometers can be connected with the mains supply to give a reference frequency. The oscillograph employs a compact-source ultra-violet lamp recording up to 15 traces on six inch wide sensitized paper. The images are developed spontaneously within a few seconds. A footage selector switch is provided which stops the drive after 2, 5, or 10 feet of paper have been exposed, or to allow continuous running. The position of each trace on the paper can be simply adjusted through an opening in the top cover using a screwdriver, while the resultant change on the paper is observed through the front window. If less than the full number of channels are in use, unwanted traces can be directed off the edge of the paper. To identify the traces, a sequential interruption of each trace provides identification of each channel at two-foot intervals, irrespective of paper speed. Five types of pencil galvanometer are available with the oscillograph, the standard general-purpose type giving response up to 1000 cycles with a tolerance of $\pm 1\%$ and a sensitivity of 7.5 mA/cm. Other galvanometers permit recording of frequencies up to nearly 2000 c/s. The amplifiers and power supply units have been designed specifically for the oscillograph, and if required can be assembled into modules for desk or rack mounting.

Hand-set synchronous timer, type HR. Electrical Remote Control Ltd., Harlow, Essex.

Timer type HR consists essentially of a synchronous motor with friction clutch, shaft with cams operating contact piles, external time setting knob with dial, back insulating panel with terminals and metal sleeve protecting mechanism of the timer. The time setting is achieved by turning the knob on the time dial until the pointer indicates the required timing period. While the timing is in progress the pointer travels towards zero position, giving indication of unexpired time. On reaching zero position internal contacts are operated and the motor of the timer is stopped. The pointer has to be set by hand for every operation. The timer can be provided with a dial for practically any time range between 0-30 seconds and 0-7 days. Standard switching capacity is 5 A at 230 v a.c., but contacts switching up to 12 A at 230 v can be provided. Applications include process control, washing machine control, timing of heating, moulding, plating, etc.

Notes and comments

History of flow measurement by pressure-difference devices

We have received a publication, under the above title, which consists of a reprinting of a series of articles, the first of which appeared in the very first number of *Instrument Engineer* in April 1952, and the last in October 1959. It consists of seven parts under the headings: The work of Venturi, The part played by Clemens Herschel, The development of the Venturi meter and some notable installations (by W. G. Ardley, formerly Joint Managing Director, George Kent Ltd.). The development of Venturi recorders from 1894 to 1911, The commercial metering of air, gas and steam (by John Lawrence Hodgson, B.Sc., Assoc.M.Inst.C.E.), Further diaphragm-operated instruments, including steam meters (by H. J. Gray, formerly Development Engineer, George Kent Ltd.), Developments in differential pressure flow measurement (by H. E. Dall, Research and Development Department, George Kent Ltd.). It also contains nine appendices which give the theory of various instruments mentioned.

This publication does not claim to 'do more than scratch the surface of so wide a subject', but it should certainly prove of interest to those whose work brings them into the measurement field'.

It is published by George Kent, Ltd., and the price is 10s.

I.T./B.P.A. one-day conference

The Society of Instrument Technology and The Birmingham Productivity Association are holding a One-Day Conference, at The Birmingham College of Technology, Gosta Green, Birmingham, on Wednesday 29th March 1961.

The main purpose of this Society is to promote greater knowledge of instruments by the presentation of lectures and series of papers upon the application of instruments and control to industrial processes and manufacturing units will be presented by engineers experienced in this work. Questions will be invited, and several histories of the improvements resulting from a more scientific system of measurement and control will be recounted and these histories related to the production problems which were resolved.

The lectures will stress (a) increased productivity using the same labour force, (b) consistent quality of products by controlled measurement, (c) reduction of scrap, during processing, by in-line inspection, including non-destructive testing.

An exhibition of the simple types of equipment which can effect improvements in production will be held and this will be closely related to the papers presented and the examples of installations which are recounted.

Convention on television and film techniques

A convention on television and film techniques, jointly organized by The Television Society and The British Kinetograph Society, will be held at The Institution of Electrical Engineers, Savoy Place, London, W.C.2, on 20th and 21st April 1961.

The convention will present some distinguished speakers both from Great Britain and from Overseas. A full programme of demonstrations is also planned. A noteworthy

feature of the convention is that a considerably longer period than is normal has been set aside for discussion following each lecture, it being realized that delegates will welcome this innovation.

Full details of the convention and registration forms are available from: The Convention Secretary, The Television Society, 166 Shaftesbury Avenue, London, W.C.2. The registration fee for the convention is three guineas which includes the cost of a copy of the Convention Proceedings and discussion.

Second conference of x-ray analytical methods

A conference will be held on x-ray analytical methods in conjunction with the Department of Geology at The University, Manchester, from Monday 20th March to Friday 24th March 1961.

This year the Conference will discuss and evaluate the latest techniques and instrumentation of x-ray fluorescence analysis. An extensive range of modern equipment will be available for demonstrating the principles of these methods over a wide field of applications.

Full information concerning the conference together with details of the registration fees may be obtained from the Conference Secretary at Research & Control Instruments Ltd., Instrument House, 207 King's Cross Road, London, W.C.1, to whom all inquiries and applications should be addressed.

Euratom, U.K.A.E.A. and U.S.A.E.C. set up translation pool

The European Atomic Energy Community (Euratom), the United Kingdom Atomic Energy Authority and the United States Atomic Energy Commission have agreed to pool their efforts to collect and disseminate information concerning translations of nuclear literature, especially from such languages unfamiliar to Western readers as Russian and Japanese. A central information office 'Transatom' has therefore been established at Euratom's Brussels headquarters. It will function in two ways: first, by publishing from December 1960 onwards a monthly *Transatom Bulletin*, which will list existing translations recently reported to the Brussels office as well as new translations planned by international or national institutions and private firms in the European Community, the United States, the United Kingdom and in other countries.

Secondly, all data relating to translations, including those made before the establishment of Transatom, are being collected and recorded in a master file system at Brussels. Copies of this card file have been offered to appropriate institutions in countries with great interest in the nuclear field.

Contacts have been established in order to avoid duplication of work when the European translation centre, to be established at Delft, Holland, is set up. The scope of this institution is much wider: it will cover all scientific and technical material in the field of exact sciences.

The *Bulletin* is available on a subscription basis from Transatom, 51 Rue Belliard, Brussels, Belgium, at \$8 per annum, \$16 air mail.

Forthcoming publication of the proceedings of the 1960 PICC symposium, Rome

The symposium on the numerical treatment of ordinary differential equations, integral and integro-differential equations took place in Rome during the week of 20th–24th September 1960 at the Mathematical Institute of the University of Rome. This symposium was organized by the Provisional International Computation Centre (PICC).

The symposium opened with a remarkable report delivered by Professor Walther of Darmstadt (Germany) on the methods presently employed in the treatment of integral and integro-differential equations. Dr. Genuys (Paris) then presented a second report, on the methods of treating ordinary differential equations. After this introduction, more than fifty specialists, divided into three study groups and lectured on their personal studies, exposing the particular problems with which they dealt and how the practical and theoretical difficulties which they encountered had been overcome.

Professor Lanczos (Dublin) delivered a more general lecture on the possibilities offered by modern electronic computers and the final session was consecrated to an outstanding speech by Professor R. Courant of New York, who exposed his personal conclusion on the requirements of scientific research in our highly technical century, as well as the problems posed by the training of young specialists in the field of automatic computation.

The symposium, on the whole, presented a fairly complete picture of the actual state of this important section of mathematical sciences. It was attended by about 200 eminent mathematicians from twenty different countries.

The *Proceedings*, consisting of about 700 pages of high scientific value, will be published by Birkhäuser Verlag (Basel/Stuttgart) at the beginning of 1961.

Second International Conference on Materials Handling

The Second International Conference organized by the Institute of Materials Handling is to take place in Southport from May 10th to 12th at a time of particular importance for British production.

The Conference will be the second devoted to materials handling and it was because the first, held in May 1959, was such a success that the Institute has decided to hold another.

The Conference will provide a forum for the international exchange of knowledge and experience and the opportunity to discuss new methods and trends for the future in a field vital to delegates of all countries whose participation will give the conference its international flavour.

Brochures may be obtained from the Institute of Materials Handling, 32 Watling Street, London, E.C.4.

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NOTES AND NEWS

Notes and comments

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he high-precision isotopic analysis of uranium hexafluoride

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Abstract

Several factors limit the precision and accuracy which can be achieved in the isotopic analysis of uranium hexafluoride by a mass spectrometer. These include inadequate resolution, memory errors, statistical fluctuations in ion currents, amplifier noise, current noise, inefficient collection of ions, voltage coefficients in resistors and chemical contamination of samples. A description is given of a 90° sector field mass spectrometer of 30 cm radius, which has been built and used to investigate the accuracy which can be achieved in practice. The precision (1 σ) of this instrument when measuring the fractional difference in isotope ratio between two samples is 5×10^{-5} at the 1% level of enrichment and 1.4×10^{-4} with natural uranium, for comparisons lasting 12 minutes. By suitable design of ion source and inlet system, the memory error in the measurement of the concentration difference between two samples has been reduced to $\pm 0.3\%$ of the difference.

1. Introduction

THE impetus for the development of refined techniques of isotopic analysis came from two sources. Firstly, there has been a growing interest in variations of the natural isotopic abundance of light elements which may have geological or geological significance. Secondly, these techniques were required by the atomic energy projects which had to handle enriched isotopes, particularly of uranium, on an increasing scale. Precise isotopic analysis owes a great deal to Nier (1947), whose mass spectrometer contained a neat form of double-focusing assembly similar to that described by Nier, Ney and Inghram (1947). This arrangement allows both ion beams to be collected simultaneously and compared by a single method, thus reducing the effects of source instability, and enabled him to quote figures for the isotopic analysis of carbon dioxide and nitrogen which indicated precisions of 0.06–0.12% (1 σ) for a single measurement of the fractional difference in isotope ratio. Wiley (1949), using a consolidated-Nier mass spectrometer of similar design, was able to achieve precisions of 0.03% in similar determinations, paying particular attention to the stability of electrical supplies, and by introducing a vibrating-reed electrometer to measure the smaller ion current, McKinney *et al.* (1950) were able to obtain precisions of 0.01–0.02% consistently. This accuracy was maintained in a notable series of papers, in one of these Craig (1953) analysed a series of carbon dioxide samples with precisions of 0.005–0.01% for a single comparison.

* Communications should be addressed to Dr. A. N. Hamer.

Unfortunately, not all the light elements of interest form volatile compounds which are chemically unreactive, and their introduction into a mass spectrometer may seriously affect its performance; corrosion of the ion source may produce instability, and chemical or physical interaction with the surfaces of the vacuum system may cause severe memory effects. This is made evident by the inferior precisions quoted for the analyses of such elements as boron during the same period, as shown in Table 1. These accuracy figures are not necessarily strictly comparable, since the times required to achieve a particular precision are not always stated in the original references, and hence the relative merit of different analyses in the Table may be in error by a factor of three if based on the listed precisions.

Table 1. Representative selection of published figures for the isotopic analysis of various elements

References from which figures are derived	Element	Substance analysed	Precision*
Nier (1947)	C, N	CO ₂ , N ₂	0.06–0.12
Wiley (1949)	C, N	CO ₂ , N ₂	0.03
McKinney, McCrea, Epstein, Allen and Urey (1950)	C, O	CO ₂ , O ₂	0.01–0.02
Craig (1953)	C	CO ₂	0.005–0.01
Parwel, Ubisch and Wickman (1956)	B	BF ₃	0.2
Reynolds and Verhoogen (1953)	Si	SiF ₄	0.04
Wanless and Thode (1953)	S	SO ₂	0.02
Owen and Schaeffer (1955)	Cl	CH ₃ Cl	0.2
Bate, Miller and Kulp (1957)	Pb	Pb(CH ₃) ₄	0.2

The isotopic analysis of uranium, in the form of its volatile hexafluoride, is particularly difficult, because not only does its chemical reactivity lead to the deposition of solid uranium fluorides which cause memory effects and source failure, but the small relative mass difference of the isotopic UF₅⁺ ions means that high precision must be achieved under conditions of high resolution. Few published data for this kind of work are available because it has been monopolized by the various atomic energy projects. Table 2 includes the results obtained in this laboratory at two levels of enrichment and the best published figures known to the authors.

The best published work on the analysis of uranium by solid-source techniques is by Lounsbury (1956), but because of the difficulty of comparing solid samples under identical conditions, the precisions obtainable at present are not

* Precision of a single measurement of the fractional difference in isotope ratio (1 σ) (%).

comparable with the results of gas-source mass spectrometers, and no further mention will be made of solid-source mass spectrometry.

The present paper summarizes the results of a prolonged investigation of methods of measuring small differences in

Table 2

References from which figures are derived	Precision*	
	$R \approx 138$	$R \approx 1$
Warren and Smith (1958)	0.055	—
Kauffman and Tabor (1959)	—	0.018
Hamer and Robbins (1960)	0.06	—
Present authors (unpublished), using an A.E.I. M.S.2 15 cm radius instrument	—	0.017
Present work (single sample)	0.014	0.005

the uranium-235 abundance of samples of uranium hexafluoride, with particular reference to the performance of a single-focusing, 90°, 30 cm radius mass spectrometer built specially for the purpose.

2. Resolution requirements

To achieve high precision when comparing isotopic abundances, a mass spectrometer must possess sufficient mass dispersion to allow the appropriate ion beam to be collected without interference from ions of the adjacent masses, and in spite of small variations in its position and profile resulting from tuning instability and varying electrical fields in the source region. The situation arising during the double collection of ions of adjacent masses is shown in Fig. 1. The

the plane of the collector slit with unit magnification, but practice the refocused beam width b is somewhat greater than w because of the existence of various aberrations ϕ , most of which are functions of the radius of curvature ρ . Thus:

$$b = w + \Sigma \phi. \quad (1)$$

The effect on the resolution of changing ρ depends on the relative magnitudes of the two terms contributing to the image width. If $w \gg \Sigma \phi$, doubling the radius of curvature doubles the ratio D/b ; but if $w \ll \Sigma \phi$, little advantage is to be gained as far as reducing interference from the adjacent ion beam is concerned. However, the stability which is required of the electrical tuning circuits is defined by the need to keep the refocused beams within the confines of the slit, width l , which in practice is usually made equal to the dispersion. The permissible fluctuation (Fig. 1) of $\pm(l - b)/2$ corresponds with a fractional tuning instability of $\pm(l - b)/2$ in the accelerating voltage. When $l - b \ll b$ the expression is very sensitive to changes in b , which means that in cases where the resolving power is barely adequate, a small reduction of the refocused beam width may ease the stability requirements of the tuning supplies profoundly. A similar argument applies to the effects of changes in beam shape.

Eqn (1) can be expanded to indicate the principal aberrations:

$$b \approx w + \rho \alpha^2 + \frac{\rho \delta v}{V} + f(\rho) \quad (2)$$

where $\rho \alpha^2$ is the spherical aberration associated with a pencil of ions diverging with half-angle α , $\rho \delta v/V$ is the chromatic aberration caused by a spread δv in the initial energy of the ions subsequently accelerated through a potential V , and $f(\rho)$ is the image curvature caused by variation of the density of the magnetic fringing flux across the pole gap and by ions passing obliquely through the central plane. Thorburn and Robbins (1960) made a detailed investigation of the aberrations present in the image of a standard A.E.I. type M.S.S. spectrometer with a 15 cm radius of curvature and showed that the size of the aberrations was not much greater than the undistorted image width w , so that a significant gain in performance can be expected if ρ is increased. Moreover, if two instruments with comparable analyser field strengths are to focus the same ions, an increase in radius of curvature means an increase in the associated accelerating voltage. Thus if care is taken to design the source in such a way as to give rise to the same spread in initial energies δv , at the new value of V , the effect of chromatic aberrations will have been reduced. On the other hand, an increase in the radius of curvature calls for more stringent vacuum standards, since the length of the flight path of the ions is proportional to ρ and the size and cost of the instrument as a whole are increased. Balancing these various factors, an increase in radius from 15 to 30 cm seemed to offer a worthwhile return, and this has been amply justified by the results quoted in §7.

After the magnet in the present machine was installed, shims were added to give a degree of second-order focusing (see, for example, Barnard 1953), and this facility results in a further small reduction in the size of the image. At present the refocused beam width, to 0.1% maximum peak height at mass 330, is 0.45 mm compared with a dispersion of 0.91 mm.

Attention must also be given to the dimensions of the slit in the no. 2 collector plate, which should be sufficiently long to ensure that small displacements of the ^{235}U ion beam in the direction of the magnetic field do not cause variations

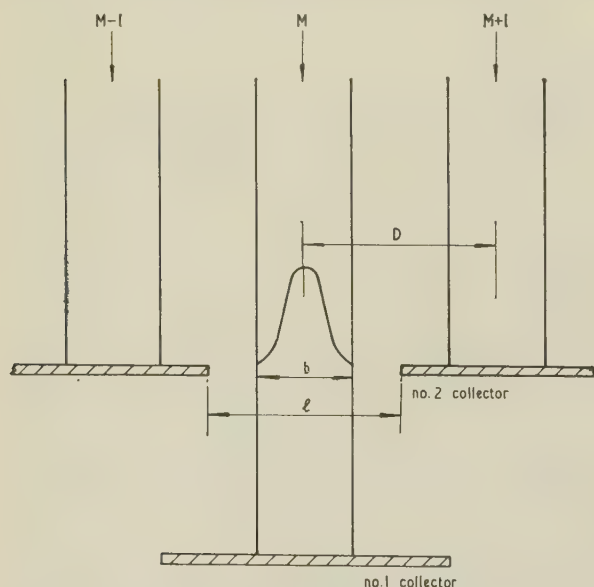


Fig. 1. Situation arising during the double-collection of adjacent masses.

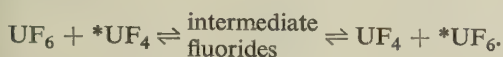
greater the dispersion D , compared with the width of the refocused beam b , the more satisfactory will be the analysis. A perfect symmetrical single-focusing mass spectrometer would produce an image of the source of ions (width w) in

* Precision of a single measurement of the fractional difference in isotope ratio $R\{(\text{U}238 + \text{U}236 + \text{U}234)/\text{U}235\}$ (1 σ) (%).

the double-collection balance position. Alternatively, the motion of ions may be restricted by a cut-off plate before it reaches the collectors.

3. The influence of memory effects and corrosion on source design

It has been known for some time that isotopic analyses on a mass spectrometer are liable to error arising from a phenomenon known as 'memory' which causes the measured isotopic composition of a sample to be biased towards that of the sample previously analysed by the instrument. Examples of this are described by McKinney *et al.* (1950) for carbon dioxide, Kirshenbaum (1951) with hydrogen, Bentley (1957) with boron trifluoride. This consecutive contamination is very marked in the case of uranium hexafluoride, and is believed to be caused by an isotopic exchange between uranium hexafluoride and solid deposits of uranium hexafluoride on the surfaces inside the spectrometer, according to the scheme



This reaction will proceed rapidly at the temperature of the ion source, and the decomposition of the intermediate fluorides can be observed as a delayed decay of the collected ion beams when the sample is removed.

To assess the size of the memory effect it is convenient to define the memory error m by the relation

$$\Delta C = (1 + m)\Delta C' \quad (3)$$

where $\Delta C'$ is the measured concentration difference for two samples whose true concentration difference is ΔC . With this definition, the memory error is independent of concentration; it has been found by experiment to be more or less constant over short periods of time, provided that a standard measurement is used to compare the samples.

Uranium hexafluoride isotopic analyses were originally made with A.E.I. type M.S.2 spectrometers fitted with ion sources resembling that described by Nier (1940). Using a 10-minute measurement cycle, ABBA (cf. § 7), the value of m was found to be 0.1 with a general tendency to rise with source life, superimposed on which was a big fluctuation each working day; a large error (± 0.1) had therefore to be applied to the measured value of the concentration difference. Most of this memory is associated with the ion source, and its magnitude is caused by the enclosed nature of the ionization chamber in which sample molecules make, on average, about 100 wall collisions before escaping. This performance was improved considerably by the introduction of the 'molecular beam' source described by Robbins and Knight (1958) and McKnight (1960). The majority of M.S.2 spectrometers within the United Kingdom Atomic Energy Authority have now been fitted with this type of source, and have reduced memory errors of $m = 0.03 \pm 0.02$. The design of the present ion source (Hamer and McCormick 1960) embodies two main principles. First, no opportunity is given to in-flowing uranium hexafluoride molecules to impinge on a hot metal surface before they enter the ionizing region; secondly, the pumping speed in the ionizing region is so high that the chance of sample molecules re-entering the electron beam after collision with surrounding walls is small. This source is a modification of the standard molecular beam model, and is illustrated in Figs 2(a) and 2(b).

Sample molecules pass from the control leak to the ion source through a short length of narrow diameter pipe, the last section of which consists of a thin-walled tube of alumina of 1/16 in. internal diameter. The end of this tube is situated 1–2 mm away from a circular orifice in the thin upper wall of a copper channel. Gas molecules issue from the end of the ceramic pipe as a molecular beam, and the majority pass through the orifice into the electron beam which runs along the centre of the channel. The configuration of the system is such that any molecules which do strike the hot upper surface of the diaphragm have a much greater probability

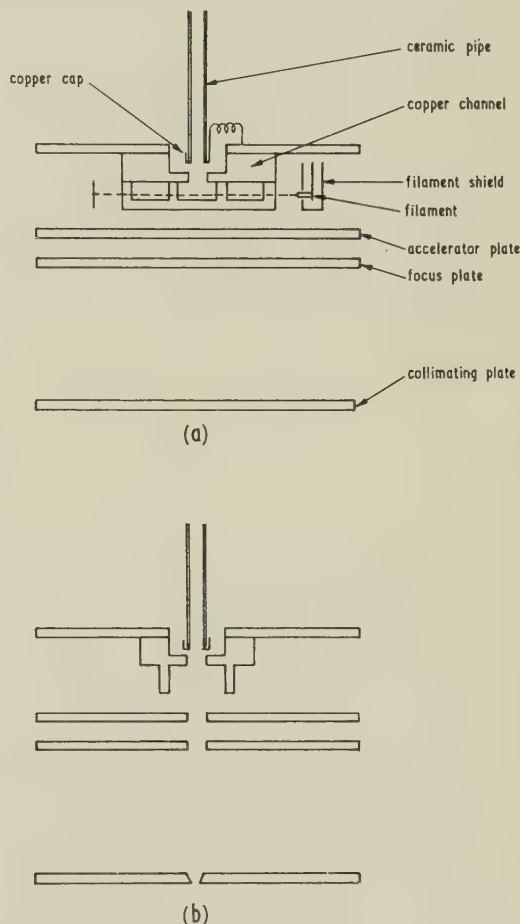


Fig. 2. Modified molecular beam ion source: (a) side view, (b) end view.

of being pumped away to the cold trap wall than of finding their way through the orifice into the ionizing region below. The only purpose of the diaphragm is to define the potentials in the source region; in order to prevent the possibility of field penetration from charge building up on the end of the ceramic pipe, the latter is fitted with a small copper cap (Fig. 2(a)) which is connected electrically to the ion source. The walls of the ionization chamber are cut away to leave a skeletal structure with the result that, on average, a molecule makes only 2–3 collisions in this region before it is pumped away. The success of this arrangement is shown by the fact that the new value of m is 0.004 ± 0.003 . The memory behaviour of this source compared with that of an original Nier-type source is illustrated in Fig. 3.

The sensitivity of the source is maintained by increasing

the size of the electron beam to 1 mA and aligning it carefully with respect to the orifice. This is achieved by means of a V-shaped tungsten filament situated in a simple electrostatic lens; with this arrangement more than 95% of the emitted electrons are transmitted along the channel to the trap. To maintain the resolution under these conditions, the strength of the collimating magnet has been increased to about 700 gauss. The effect of changes in geometry on field penetration into the ionization chamber was studied by plotting equipotentials by the 'relaxation method'. In this way it was possible to design the source with a small field gradient in the ionizing region, with the result that the

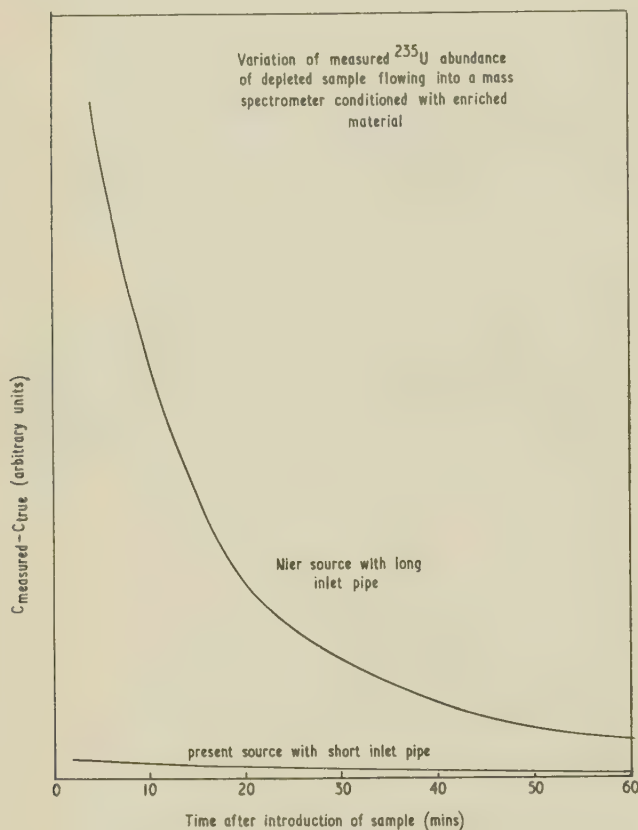


Fig. 3. Effect of memory on the measured uranium-235 concentration of uranium hexafluoride.

chromatic energy spread of ions accelerated with 6 kv is less than 2 v. The ion gun was designed to give a well-defined ion-beam cross-over in the vicinity of the first slit. The cross-over acts as the source point of the analyser, and the collimator slit then acts as a simple aperture to define the angle of divergence of the ion beam.

An important economic factor in the isotopic analysis of uranium hexafluoride is the limited source life resulting from the formation of electrically insulating films of solid uranium fluorides. These films produce polarization effects which cause drift and instability in the ion beam and make the source unusable. When this occurs, the only remedy is to remove and clean it. Since these effects are most serious in the ionizing region, the molecular beam source would be expected to show an improvement in source life on account of its small surface area; and this has been found to be the case. Comparative experiments have shown the molecular beam sources to have a fourfold increase in source life

compared with the original design, when operated in normal A.E.I. M.S.2 spectrometers under the same conditions. However, at the time of writing we have not been able to maintain the precisions quoted in § 7 in our 30 cm radius mass spectrometer for more than 100 hours source life. It is probable that the short life can be avoided by minor changes in the electrode system.

The life of a source in the presence of uranium hexafluoride is greatly affected by the nature of its component and in practice copper has been found to be a satisfactory constructional material. In this respect, bulk chemical resistance is not a reliable criterion, since sources made from such highly resistant metals as aluminium and platinum have been found to become unstable in a matter of hours. This is because the inertness of these metals depends on the formation of a resistant film of metal fluoride, and it is the electrical properties of this film which determine the behaviour of the metal in an ion source. Since the growth of uranium deposits is affected by the amount of residual water and organic material in the vicinity, it is important that the vacuum standard shall be as stringent as possible, and high-temperature baking is essential.

The molecular beam ion source is likely to have useful applications in fields other than uranium hexafluoride analysis. Bentley *et al.* (1959) have already shown how a modified version can be used for the analysis of various halogen compounds, while the small number of wall collisions offers a number of advantages when examining free radicals or other labile species.

4. Important errors in the measurement of ion currents

4.1. Random errors

The fundamental limitation to precision is a statistical fluctuation in the number of ions arriving at the collector in a time equal to the time constant of the measuring system. In practice, some noise is generated in the amplifiers themselves, and current noise appears in the high-megohm resistors in the input circuit of the electrometers.

4.1.1. Statistical fluctuations in the ion beam

An important cause of noise in the observed signal at the collector is the statistical variation in the ion-beam current. In a time equal to the time constant of the amplifier, a random sample n of the ion beam is collected, and the standard deviation of the statistical fluctuation of the count is almost exactly given by the standard deviation of a Poisson distribution, namely, $\sqrt{n}$. The relative fluctuation in the measured current is therefore $1/\sqrt{n}$. An ion current of 10^{-10} amp corresponds with about 6×10^8 ions/sec passing down the spectrometer tube. If the integration time of the instrument is one second, the standard deviation of the fluctuations will be about 2.5×10^4 ions/sec; i.e. 4×10^{-5} of the observed beam size. When comparing two equal ion beams of 10^{-10} amp by double collection, the statistical fluctuation in the balance position will be about 6 parts in 10^5 . In the case of uranium hexafluoride with a natural uranium-235 concentration of 0.7%, the magnitude of the $^{235}\text{UF}_5^+$ current is only about 10^{-12} amp, and the statistical fluctuations in the double-collection balance position of 6 parts in 10^4 are caused entirely by the small size of the ion beam. This can cause a serious error which may be reduced by increasing either the magnitude of the ion-beam current or the integration time constant. In our instrument the total ion-beam current is limited to about 3×10^{-10} amp by considerations of source life, and a large gain in statistical

accuracy can only be achieved by the use of a long time constant. Increasing this to 20 seconds will reduce the fluctuation in balance position to 1 part in 10^4 for samples of natural uranium hexafluoride. When using such long time constants, reliance is placed on the constancy of the uranium-235 tuning position, and once again the importance of high resolution and stable e.h.t. and magnet current supplies is apparent. Also, to avoid an increase in the time taken to compare samples, it is arranged that the condensers applied to the balance position indicator are not discharged during the interval of pumping out samples.

2. Current noise

Even when the mean values of the ion-beam currents are constant, the observed random fluctuations in the double-collection balance position are frequently several times greater than would be expected from a statistical variation in the number of ions reaching the collector in unit time; it is believed that this effect is caused by current noise generated in the resistor whose value is about 10^{10} ohms. Current noise is normally small in metallic resistors and occurs chiefly in the semiconducting and carbon composition varieties. Unfortunately metallic resistors are not available with values above about 10^6 ohms.

One of the properties of current noise is that the power in unit bandwidth appears to be inversely proportional to frequency, and Rollin and Templeton (1953) showed that this relation holds down to frequencies as low as 10^{-3} c/s. For this reason current noise is most significant in the very low frequency range, which has important consequences when making accurate mass spectrometer measurements. Templeton and MacDonald (1953) derived an empirical equation for the current noise in a resistor:

$$\frac{\delta r^2}{r^2} = A \frac{\delta \nu}{\nu} \quad (4)$$

where δr^2 is the mean square of the apparent fluctuations in the resistance at frequency ν , r is the value of the resistance, $\delta \nu$ the bandwidth of the detector, ν the frequency of the noise and A a constant of proportionality, found to have values between 3×10^{-11} and 3×10^{-12} for a current of $1 \mu A$ passing through carbon film resistors of approximately 10 kilohms.

To determine whether current noise was significant in our instrument, the fluctuations in the double-collection balance position were compared at frequencies of 1 c/s and 1×10^{-3} c/s. It was found that Eqn (4) was obeyed, which suggests that the observed fluctuations were in fact mainly caused by current noise. In this case the double-collection balance position varied by a factor of 5×10^{-4} over a period of minutes and A was of the order of 10^{-9} . However, Hettich (1950) and others have shown that current noise depends on a number of parameters including the physical dimensions of the resistor; and for resistors from another manufacturer, A was estimated to be of the order of 10^{-10} . The results quoted in § 7 were obtained with the latter variety of resistor.

4.2. Systematic errors

Bias in the experimental results is likely to arise from two sources: inefficient collection of ions arising from an unsatisfactory design of collector system, and non-linearity in the response of the high-megohm resistors.

4.2.1. Problems in ion collection

Observations over a period of years have shown the difficulty of collecting ions efficiently when analysing samples

of uranium hexafluoride. This is particularly serious in the double-collection method in which the ^{238}U ion beam is focused for long periods at the same point on the no. 2 collector because the prolonged bombardment of a particular area of plate by UF_5^+ ions can reduce the collection efficiency for ions at that point by several per cent. Fig. 4 shows the amplifier response as an ion beam is swept over the no. 2 collector after prolonged bombardment by UF_5^+ ions.

The mechanism of this effect is not finally established. Honig (1959) has shown that, when high-energy ions are incident on a surface, sputtering occurs with the release of neutral molecules and positive ions. In addition, UF_5^+ will form monolayer deposits of UF_4 in about 100 hours of bombardment at 10^{-10} amp, and it is not surprising therefore that the fraction of sputtered or reflected ions (Brunée 1957) at this point is considerably different from that at the unaffected parts of the no. 2 collector.

In the high-precision measurements described in § 7, the two samples are rapidly compared under the same conditions, and these variations in collection efficiency do not have a direct effect on the accuracy of measurement. However, they have a serious indirect effect, making the double-collection balance position very susceptible to tuning fluctuations, because in these circumstances a slight displacement of the ^{238}U beam from its normal position will cause a marked variation in the response from the no. 2

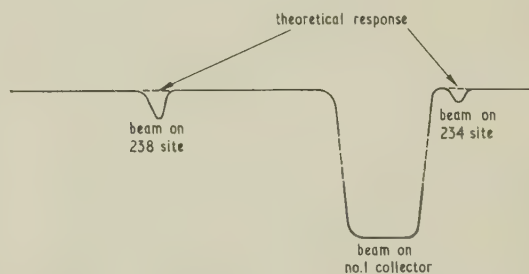


Fig. 4. Effect of deposits on the response of no. 2 collector as an ion beam is swept across the collector system.

amplifier. Thus the advantage of a wide no. 1 collector slit is lost, and the spectrometer again becomes very sensitive to changes in the e.h.t. and magnet supplies.

These effects can be eliminated by designing each collector as a Faraday cage. In this way all ions are trapped, including those which have been reflected or sputtered, and the response curve from the no. 2 amplifier assumes its theoretical shape. The present collector system is shown in Fig. 5. The no. 1 collector which traps the ^{235}U ions consists of a single Faraday cage, but the no. 2 collector is a double bucket assembly, one of which traps ^{238}U ions while the larger one collects the remaining isotopes. An electrostatic suppressor prevents secondary electron emission from no. 1 collector, but losses from the no. 2 collector are prevented by a weak external magnetic field.

4.2.2. Effect of voltage coefficients in the collector resistors

The high-value resistors used in the collector circuit often possess significant voltage coefficients of resistance, in which case the potentiometer balance position S for a particular sample can depend on the magnitude of the total ion-beam current. Let i_1 and i_2 be the ion-beam currents incident on no. 1 and no. 2 collectors, respectively, r_1 and r_2 the values of the resistors with no voltage across them, and δ_1 and δ_2 the voltage coefficients for each resistor.

Then $i_2/i_1 = R$, where R is the isotope ratio of the sample. The voltage generated across r_1 is $i_1 r_1 (1 - \delta_1 r_1 i_1)$, neglecting second-order terms, and

$$S = \frac{k i_1 r_1 (1 - \delta_1 r_1 i_1)}{i_2 r_2 (1 - \delta_2 r_2 i_2)} \approx \frac{k r_1}{R r_2} (1 - \delta_1 r_1 i_1 + \delta_2 r_2 i_2) \quad (5)$$

k being a gain factor of the amplifiers which is assumed to be the same for both samples. If the balance position is to be independent of beam size

$$\frac{\delta_1}{\delta_2} = R \frac{r_2}{r_1} \quad (6)$$

The fact that this condition cannot be satisfied for two samples with different values of R can lead to significant systematic errors.

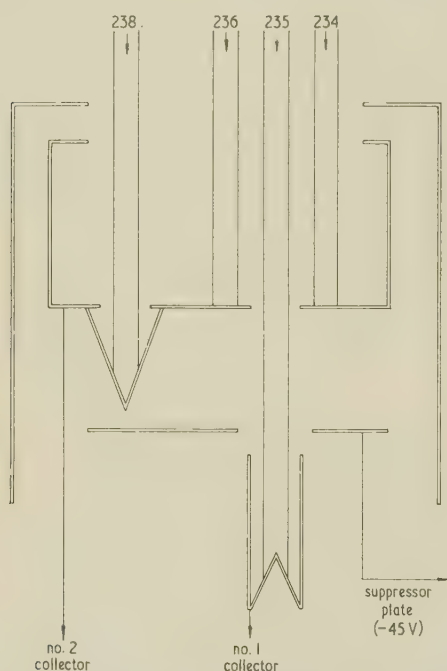


Fig. 5. Schematic diagram of present collector system for use with uranium isotopes.

Suppose two samples A and B with isotope ratios R_A and R_B are compared, the total ion beam current i being constant. The individual ion currents to the no. 1 and no. 2 collectors can be tabulated as follows:

Sample	i_1	i_2
A	$\frac{i}{1 + R_A}$	$\frac{i R_A}{1 + R_A}$
B	$\frac{i}{1 + R_B}$	$\frac{i R_B}{1 + R_B}$

Substituting these values for the ion currents in Eqn (5), for each sample,

$$R_A = \frac{k r_1}{S_A r_2} \left(1 - \frac{\delta_1 r_1 i}{1 + R_A} + \frac{\delta_2 r_2 i R_A}{1 + R_A} \right)$$

$$R_B = \frac{k r_1}{S_B r_2} \left(1 - \frac{\delta_1 r_1 i}{1 + R_B} + \frac{\delta_2 r_2 i R_B}{1 + R_B} \right)$$

$$\text{Hence } \frac{R_A}{R_B} \approx \frac{S_B}{S_A} \left\{ 1 + \frac{i(R_A - R_B)}{(1 + R_A)(1 + R_B)} (\delta_1 r_1 + \delta_2 r_2) \right\}$$

and the balance point is no longer exactly inversely proportional to the isotope ratio. In the case where $R_A = R_B = 1.01$, $r_1 = r_2 = 5 \times 10^{10}$ ohm, $\delta_1 = \delta_2 = 0.01$ per volt and $i = 10^{-10}$ amp,

$$\frac{R_A}{R_B} = \frac{S_B}{S_A} (1 + 5 \times 10^{-5})$$

and the systematic error resulting from this effect is comparable with the precision of the instrument. If, therefore, voltage coefficient errors are to be avoided, not only must the ion-beam size be held constant but the coefficients must be zero, or at least known with an absolute accuracy of 0.1% per volt.

5. General description of the instrument

The mass spectrometer is shown in Fig. 6. With the exception of the magnet, the amplifiers and some items of vacuum equipment, the various parts of the instrument including the electronic units, were designed and constructed by the Reactor Technology Branch, Capenhurst. The analyser tube has a radius of curvature of 30 cm with a deflection angle of 90° , and was formed by hydraulic flattening a length of 2 in. diameter, $\frac{1}{8}$ in. wall copper tubing. The cross section of the flattened portion measured $1.5 \text{ cm} \times 7.0 \text{ cm}$, and this large size reduces the scattering of ions at the edges of the principal beams. The ends of the analyser tube are flanged and bolted to stainless-steel chambers which house the ion source and collector assembly respectively. The tube is arranged in a horizontal plane and is held at the centre of the bend by a non-magnetic structure while the end chambers and the two pumping stacks to which they are attached are supported by a system of rollers and V grooves. This allows the thermal expansion of the system to take place without strain along the flight path of the ion beam; this may amount to 0.2 cm when baking at 300°C .

Each pumping stack consists of two demountable liquid nitrogen traps in series and an Edwards 2M3 mercury diffusion pump. In this way there is efficient pumping at both ends of the analyser tube. The two pumping stacks are backed by a single A.E.I. type DR1 rotary pump, while a similar unit is provided to evacuate the gas-handling system and the two collector resistor enclosures. The walls of the cold traps act as the principal pumping agency for uranium hexafluoride, and the proximity of one of these traps to the ion source gives a pumping speed at that point of 80 litre/sec compared with 10 litre/sec for permanent gases.

The stainless-steel flanges are soldered to the copper analyser tube with silver-copper eutectic, and elsewhere internal sealing welds are used wherever possible to prevent trapped pockets of dirt from contaminating the vacuum system. Electrical leads are introduced by means of Ferraz metal-ceramic high-vacuum seals, except in the case of the leads to the two collector plates for which Kovar seals are used. This is because ceramic seals, although possessing the necessary insulation resistance of 10^{14} – 10^{15} ohm, suffer from severe polarization effects which give spurious signals.

No organic materials are used inside the high-vacuum system, and all flanges are sealed by gold gaskets to permit high-temperature baking at 350° by external band heating. The use of thick copper for the walls of the analyser tube ensures that the centre is adequately heated by conduction as well as being sufficiently rigid at the high baking temperature. The outer surface of the tube was nickel-plated to

both of 0.0005 in. before being flame-sprayed with aluminium to a further 0.05 in. to prevent oxidation of the copper during periods of baking. It is not necessary to move the C core magnet during this operation, since the analyser tube is thermally lagged with glass tape and covered with a layer of polished aluminium foil. The pressure is measured by a D2 ion gauge mounted on the source cold trap. After a baking period of from 4 to 6 hours at 300°C the residual pressure is usually 3×10^{-8} mm Hg. The principal components of the background are N_2 , CO, O_2 and CO_2 .

were touched by a piece of ice. When necessary during the measurement cycle, samples are pumped away through a manifold containing a demountable glass liquid-nitrogen trap and a rotary pump.

The problem of gas flow in a mass spectrometer has been discussed by Honig (1945) and will not be enlarged on here. In our instrument a single leak is used to introduce the samples to the ion source and comprises a very short length of thin-walled nickel pipe compressed with variable thrust by a differential screw mechanism; at the working sample

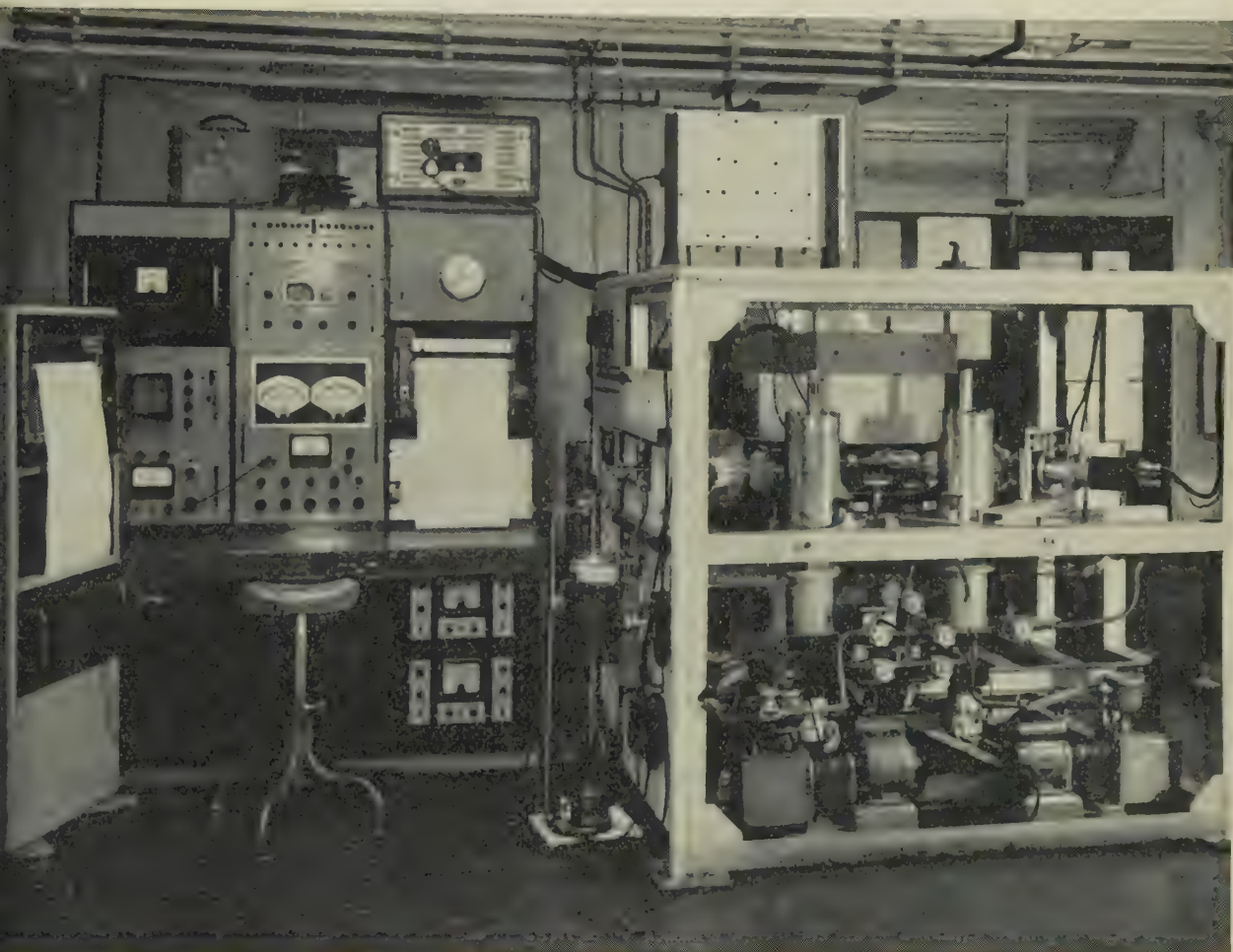


Fig. 6. General view of the instrument.

The present sample-handling system is designed to take up to 10 samples. It contains a number of toggle-operated polyethylene diaphragm valves whose bodies are part of a single block of brass; by this means it has been possible to eliminate joints between components and to reduce the surface area. Samples of uranium hexafluoride are contained in glass bak-seal tubes which are attached to the manifold by compression couplings with white J1260 rubber gaskets. The two sample tubes are mounted in close proximity and are surrounded by an ice-bath during measurements. The ice-bath is contained in a Dewar flask and is continuously stirred to ensure a steady and uniform temperature; in addition, the two tubes are surrounded by a cylinder of wet paper gauze which prevents any local temperature variation in the vicinity of the tubes, such as might occur if one of them

pressure of the order of 1 cm Hg, gas is transmitted under conditions approximating to molecular flow. Its main advantage is that it appears to have negligible memory for uranium hexafluoride. The leak is connected to the ion source by a short length of narrow tubing whose bore is a compromise between two requirements. The smaller the radius the less the area and the less the memory on the wall, while the larger the radius the quicker are samples pumped away. A typical compromise would be a radius of 1 mm for an inlet pipe 20 cm long.

After leaving the ionization chamber, the ions are accelerated through 6 kv and pass into the analyser field. This is provided by a C core magnet with a pole gap of 1.25 in. and a pole face width of 5 in. which was made by Metropolitan-Vickers Electrical Co. Ltd. (now Associated

Electrical Industries (Manchester) Ltd.). The large gap, together with the large radius of curvature of the machine, means an increase in the size of the magnet, and the present assembly weighs approximately 2 tons. As mentioned in § 2, the pole faces are shimmed with removable shims calculated to correct for the spherical aberration arising from a beam divergence half-angle of 3° . For ions of mass 300 with energy 6 kv, the magnet field is 6800 gauss, requiring a magnet current of 500 ma.

Because of the difficulty of aligning the source and collector slits in such a large instrument, provision was made to allow the complete collector assembly to be rotated (Bishop 1959) without loss of vacuum by means of external micrometer controls. The achievement of high-resolution conditions is also facilitated by the inclusion of a variable-width slit in front of the no. 1 collector. This is also adjustable from outside the vacuum system, and simplifies the setting up procedure.

The guiding principle in the design of the electronic units was reliability rather than the introduction of many novel features to the circuits, with the result that electronic troubles are very rare. Power for the electrical equipment is supplied through a Sorenson voltage regulator. The essentials of the various electronic units may be summarized as follows.

The ionizing electron current in the source is controlled by varying the temperature of the emitting filament. Power to the filament is supplied at about 1 kc/s by an oscillator-amplifier system, the oscillator amplitude being adjusted by the d.c. feedback loop which compares the trap current with a reference current derived from neon stabilizers and a resistor chain. This equipment, which also supplies the electron accelerating potential, operates at source potential of 6 kv, and is therefore mounted on a chassis which is insulated from earth. The mains supply transformer has a primary winding rated for 6 kv insulation. The chassis is connected directly to the e.h.t. supply, and forms a guard to prevent insulator leakage currents flowing in the source stabilizing circuits. For the same reason a double screened cable is used to connect to the source itself, the inner screen being connected to the e.h.t. supply. When supplied via the mains regulator, the unit controls the trap current to a short-term stability of about 3 parts in 10^5 . Also, because ionization efficiency varies considerably over the available range of accelerating voltage (50–300 v), changes in this parameter would affect the sensitivity, and to prevent this the electron accelerating voltage is stabilized to 1 part in 10^4 .

The ion accelerating potential of 6 kv is derived from a radio-frequency oscillator e.h.t. unit. This is stabilized by a resistor chain and valve d.c. amplifier, which controls the screen of the oscillator valve, with reference to 170 volts, again derived from neon stabilizers. All adjustments of accelerating potential are made on the reference voltage. This allows the use of only one resistor chain for stabilizing and deriving focusing potentials, and provides an e.h.t. supply which is always of low impedance, so that considerable fluctuations of leakage currents may be tolerated with little change of accelerating potential. In practice this remains constant to within ± 1 part in 10^5 .

The magnet current is stabilized by series valves with a chopper type d.c. amplifier and a reference voltage (10 volts) derived from a neon stabilizer fed with constant current. This arrangement, in combination with an a.c. feedback loop to reduce supply frequency ripple, gives a short-term stability of 2 parts in 10^5 .

The amplifiers for handling the collector currents are Vibron Model 51A, and were supplied by Electronic Instruments, Ltd., to our specification.

The major contribution to noise in an electrometer amplifier comes from grid current in the first valve and has a 1/f distribution at very low frequencies due to the flicker effect (Gillespie 1953). These low-frequency components are observed as an uncertainty of measurement and are generally known as 'zero drift'. Unfortunately, there is a limit to the extent to which noise can be decreased by reducing the amplifier bandwidth, because this eventually leads to a longer period between successive measurements and makes them more susceptible to the low-frequency components. In fact, so long as readings are made as quickly as the amplifier bandwidth will permit, the uncertainty of these readings is independent of the bandwidth.

In the vibrating-reed amplifier (Inghram, Heyden and Hess 1947, Palevsky, Swank and Grenchik 1947) this difficulty is overcome by means of a vibrating capacitor which 'chops' the signal before it is presented to the amplifier. After amplification the signal is then 'detected'. In this system, only the high-frequency components of valve noise are significant, and the noise is not only reduced over the required bandwidth but is practically independent of frequency. In the detected signal there is a marked reduction in the amount of noise at very low frequencies, and the noise level can be varied by altering the bandwidth of the amplifier.

The noise level of these amplifiers is about 5×10^{-16} amp for a time constant of 1 second, and the variations in zero level are less than 10^{-15} amp/hour. Fluctuations of this size have little effect on the accuracy of measurement, being less than the effects of current noise and the statistical variation in the arrival of ions discussed in § 4.

Two identical amplifiers are used for measurements by the double-collection technique. Their rise times are continuously adjustable, and this facility can be used to match the time constants, thereby obtaining a significant reduction in that part of the noise originating from source fluctuations.

A self-balancing potentiometer recorder is used to measure the ratio of the amplifier outputs as shown in Fig. 7. Additional smoothing common to both amplifying channels is provided by a capacitor and an associated buffering resistance.

Additional facilities are provided for setting up the instrument. These include wide range scanning and logarithmic-scaled recorder for spectrum plotting. A Mill circuit applies a slowly varying reference voltage to the magnet current stabilizer to give scanning rates down to 0.01% per second. A logarithmic slidewire in the form of a ladder network attenuator, and connected as the feedback potentiometer of the no. 1 amplifier is fitted to a standard self-balancing recorder. The servo system maintains the output of the amplifier at a fixed reference voltage, so that the recorder scale gives the logarithm of the amplifier output over about $3\frac{1}{2}$ decades.

An oscilloscope with a long persistence screen can be used to show peak shapes while making resolution adjustments. Scanning for this purpose is by variation of the ion accelerating potential. An alternative method of measuring isotope abundance ratios is by using the oscilloscope to compare peak sizes on a single-collection system, and automatic switching of the amplifier gain control enables the operator to set ratio meter dials for equal peak heights presented on the oscilloscope.

To cater for the many ways in which it may be desirable to use the various measuring units in a research instrument, a very flexible system of operation selection is provided. Connections to the two amplifiers, gain control potentiometers, oscilloscope unit and a chopper amplifier galvanometer are made through a selector switch.

er are brought to a panel-mounted 18-way socket. For h mode of operation an appropriately wired plug is used, which the external equipment may also be attached.

6. Preparation of samples

amples for analysis are already in the form of uranium afuoride, while the isotopic standards prepared in the oratory in the form of U_3O_8 are converted to uranium afuoride by fluorination with chlorine trifluoride at a ssure of 0.5 atm and a temperature of 150° c in nickel

with few exceptions, fluorocarbon spectra increase in intensity towards lower masses. By studying the cracking patterns of a variety of fluorocarbons, it is apparent that the intensity of the characteristic ion $C_4F_7^+(m = 181)$ is at least an order of magnitude greater than that of the dominant ion in the mass range 329–334 (i.e. mass 331), and usually two orders of magnitude greater than those of the ions at masses 330 and 333. Small quantities of fluorocarbons can be removed by the procedure already described for light gases, but if serious contamination has occurred the samples must be rejected.

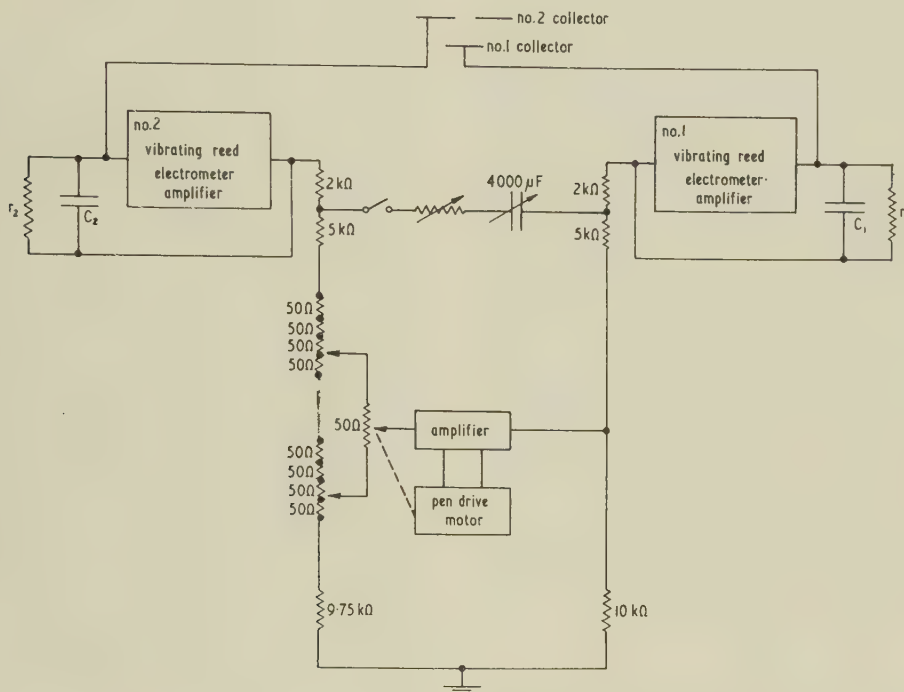


Fig. 7. Balancing network in the double-collection recorder.

sels. Samples of uranium hexafluoride are kept in clean, Pyrex glass break-seal tubes containing a small amount odium fluoride powder to act as a getter for any hydrogen ride which may be present in the samples.

fter the tubes are attached to the inlet system, it is ssary to ensure that the samples are clean. Traces of t gases such as air and hydrogen fluoride can be removed repeatedly warming the sample, freezing to -78°C and mping, etc. This is necessary because their presence in of a pair of samples could cause error by pressure broad- ing or by an alteration in the flow of uranium hexafluoride the instrument, resulting in voltage coefficient effects.

error can also arise from fluorocarbons with fragment hich interfere with the UF_5^+ ions used in the analysis. ally they contribute less than 10^{-15} amp, and in any case, vided that they are generated inside the mass spectrometer, ll quantities will not affect the accuracy with which the ntration difference can be measured, since the effect on n samples will be the same. On the other hand, if the urity is present in one of the samples only, an error will ntroduced; if the highest accuracy is required it is ssary to scan each sample. Since the interfering ions ot be observed directly, use is made of the fact that,

7. Operation and performance of the instrument

Under normal conditions of operation, samples A, B are exchanged once every three minutes according to the scheme ABBA, the sequence of operations during each part of the cycle being:

Time (minutes and seconds)	
0.00	} pump out previous sample
0.15	
2.00	} introduce new sample.
3.00	

The output of the double-collection balancing potentiometer is monitored during the third minute, the centre of the best straight line through the trace being a measure of the uranium-235 concentration in the sample. When two samples are being compared, the fractional difference in isotope ratio $\Delta R/R$ is given directly by the fractional change in balance position $\Delta S/S$. A single determination of $\Delta R/R$ involves one complete cycle of sample interchange ABBA, and lasts 12 minutes.

The precision of the instrument was tested at two levels of uranium-235 concentration by repeatedly comparing a

sample against itself. A series of 120 measurements was made at the 46% level at intervals during a period of three months, and the standard deviation of a single determination was found to be 5×10^{-5} . A similar set of 250 measurements at the natural level had a standard deviation of 1.4×10^{-4} , which is close to the theoretical limit set by the statistical arrival of ions at the collector.

Although tape control of operations and digital print-out facilities are also now available, it is quite easy for a single operator to achieve these precisions in their absence without fatigue over a considerable period of time. His main duties are to operate the valves of the sample-handling system at the beginning of each three-minute period, and to take readings from the chart of the balancing potentiometer; e.h.t. supplies must be adjusted not more than once an hour, and the beam size corrected rather less often. If the instrument is operated in sub-normal conditions, it is also necessary to note the actual value of the beam size during the reading minute, so that a marginally significant voltage-coefficient correction can be made.

The nature of the dominant error in the measurement of an isotopic enrichment depends on the size of the concentration difference. If this difference is large, the principal error is caused by the uncertainty $\pm \delta m$ in the value of the memory error m defined by Eqn (3). In the present instrument $m = 0.004 \pm 0.003$. Thus when the value of ΔC is less than 1% the uncertainty in memory is negligible, and the precision of measurement depends on the instrumental precision already discussed, together with the similar but slightly larger effects arising in the sample-handling system. These consist of variations of the measured concentration difference between the samples, which can occur to the extent of 1–2 parts in 10^4 . Their cause is not yet understood, but they usually appear after the physical state of the uranium hexafluoride has been altered, for example, by freezing down the sample between periods of measurement.

8. Conclusion

The instrument described can achieve a precision of 5×10^{-5} (1σ) in the isotopic analysis of uranium at the 50% level of enrichment, with little effort on the part of the operator. The principal factors which affect the precision are adequate resolution, the efficient collection of ions, the random arrival of ions at the collector, and current noise in the collector resistors. With the ion source and inlet system which have been constructed, the memory error in the measurement of the concentration difference between two samples is only $\pm 0.3\%$ of the difference.

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successful version of the Beevers-Macewan Fourier synthesizer using dekatron counters

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Abstract

A modified version of the Beevers-Macewan machine using dekatron counters is described. The machine calculates a Fourier synthesis on exactly the same principle as the Beevers and Lipson strips. A switch selects Cos or Sin; one set of push buttons selects the term number (0-99) and a second set selects the amplitude (0-100). On pushing the + or - button the machine adds or subtracts the numbers on the corresponding strip to 16 counters simultaneously. When all the terms have been added or subtracted the result for 0-15/60 of the period, in steps of 1/60, is registered on the counters, negative numbers being shown as complements.

The main difficulty in previous designs, which had not been surmounted, was to obtain reliable counters which would work backwards as well as forwards and could be quickly zeroed. This has now been accomplished by using dekatron counters and running the Post Office selector switch at 20 steps per second, the maximum for a single stepping operation. A term of amplitude A thus requires 5 seconds to put in, but a term of amplitude 10 takes under 1 second because the function-generating uniselector finishes the rotation from position 0 onwards at its normal speed of 200 positions per second.

1. Introduction

THE title indicates that the machine to be described has had a chequered history. The principles were first described by Beevers (1939) and a detailed description of a working model given by Macewan and Beevers (1942). Unfortunately the means of displaying the results—16 counters—were not available and although no great difficulty was expected in the way of obtaining suitable counters they in fact remained unobtainable until today.

The first version of our machine was completed about 1950 and successfully exhibited at the 1951 Physical Society exhibition. One has to qualify the 'successfully' by saying that while our 16 'home-made' counters registered faithfully, the zeroing mechanism could not be ganged up to work simultaneously on all 16, so that the counters either had to be zeroed individually or the zero position regained by taking out the terms which had been put in. The machine was used to some extent, even in this condition,* but the poor reliability of the counters in protracted use was an even greater drawback than the zeroing procedure.

All our efforts to improve the counters, including incorporating commercial registers, failed to solve the problem until the provision of a grant from the Paul Instrument

According to a verbal communication, a machine functioning in this way has been constructed in Utrecht University.

Fund enabled dekatron counters to be constructed. The opportunity was taken to reconstruct the Post Office gear under the guidance of the Mechanical Development Group of A.E.I. (Woolwich) and this part of the machine now contains only circuits which are standard P.O. practice. The machine is now in full operation and was exhibited at the International Crystallography Congress in Cambridge in 1960.

The description which follows will be better understood by a preliminary reading of the paper by Beevers (1939) and of the first two sections of the paper by Macewan and Beevers (1942), including the description of the P.O. switches. The details of the Macewan and Beevers machine are considerably different from those of the present one; the major differences are discussed in § 5.

2. Principle and design of the machine

The machine sets up on 16 counters the numbers on the Beevers-Lipson (Beevers and Lipson 1936) strips and as each term is added in, the counters accumulate the numbers, finally presenting the totals for

$$y = \sum_{H=0}^{99} \left(A \cos 2\pi H \frac{n}{60} + A' \sin 2\pi H \frac{n}{60} \right)$$

at integral values of n from 0 to 15 and for integral values of A from 1 to 100, exactly as they would be obtained by totalling the columns of a set of strips, except that negative numbers are presented as complements.

Post Office uniselector switches are used both to generate the fundamental term $A \cos 2\pi n/60$ and to redistribute the results to obtain the harmonics. The values of the function $A \cos 2\pi n/60$ are given to the nearest integer. Therefore as $A \rightarrow A + 1$ the value of the function either increases by 1 or remains constant. Mechanically the increase from $A \rightarrow A + 1$ corresponds to the uniselector stepping on from the A th row of contacts to the $(A + 1)$ th row. The wiring of this row of contacts is arranged to control high speed relays so that where the function increases by 1 the corresponding counters receive a pulse and the others do not. Thus as the uniselector steps on from 1 to 100 it reproduces, one after the other, the corresponding strips on the 16 counters. When the specified amplitude is reached the pulses are cut off and the required values are left on the counters.

Further description can best be done in conjunction with the wiring diagrams.

3. Operation of the machine

Figure 1 shows the control desk. The Cos/Sin switch at the top right is set to the function required. The values of H (00-99) are put in by pressing the appropriate tens and

units buttons of the first two rows. The amplitude A is put in on the second set of buttons. The $+$ or $-$ start button is pressed as required and the unselector steps round to the designated amplitude at a rate (controlled by the pulsing unit) of about 20 c/s. It then homes at its full speed of 200 c/s. An average term thus takes 2 to 3 seconds to put in.

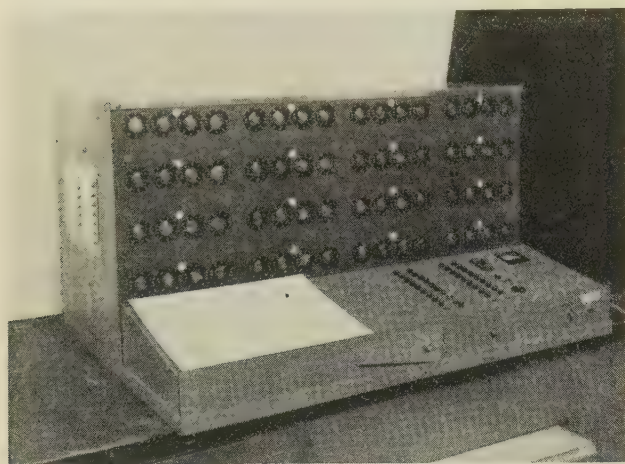


Fig. 1. Photograph of the machine showing the control desk.

As soon as the start button is pressed the wave number H can be altered for the next term up to $H = 15$, but the amplitude buttons must not be altered until the previous

amplitude has been reached. From $H = 16$ upwards neither set of buttons must be altered until the previous amplitude has been reached.

4. Description

4.1. Post Office equipment and controls

Figure 2 shows the schematic wiring diagram. All relay contacts in this and other diagrams are shown in the unenergized position. The master pulser consists of a number of disks rotating on the shaft of a shaded pole motor at 1200 rev/min. Segments cut out of the disks allow contacts to close and open in a controlled sequence.

A detailed description is given in § 4.3.

4.1.1. General description of the sequence of operations

The sequence of events on pressing the start $+$ button is as follows:

- The 50 v supply is connected to A2.*
- Master pulser contacts 1P close and A2 is energized.
- 1A2 closes locking A2 on and 2A2 closes so that the supply reaches the latch coil of unselector I.
- Master pulser contacts 2P close and unselector I steps on 1 row.†
- As the unselector moves from its zero position the homing contact set operates. The 'zero break' contacts close and the 'zero make' contacts open. The closing of the zero break contacts has no immediate effect but the opening of the zero make contacts removes a short circuit from A1, a high speed (H.S.) 2-make relay, which immediately energizes, closing 1A1 (thus giving a supply independent of the start $+$ button to the latch coil of 2A1, which energizes A4.
- 1A4 closes and the -150 v supply for pulsing the counter is connected to the pair of pulsing contacts 4P and 5P.
- Pulsing contacts 4P and 5P close, sending pulses through such of the 14 H.S. relays as have closed contacts to the counters, via the wave number unselectors II and III.
- Pulsing contacts 3P close sending the 50 v supply through the amplitude buttons to the unselector I.
- Steps (d) to (h) are repeated until the unselector arrives at the contact row given by the setting of the A button.
- The 50 v pulse from 3P passes through the unselector to energize A3 and A5.
- 1A3 changeover operates, open circuiting A4 and locking on A3 and A5.
- 1A4 opens preventing any further pulses reaching the counters.
- 1A5 changeover operates and returns the unselector motor to normal operation. The motor moves round to zero position where it is stopped by the operation of the zero break contacts.
- 2A5 and 3A5 open as a safety precaution against a flash over while the unselector is operating at speed.
- The operation of the zero make contacts short circuits A1 and the opening of 1A1 and 2A1 returns the whole circuit to its original condition.
- It is essential that the start $+$ button shall have been released before the unselector returns to zero. For small amplitudes this means within half a second. A button

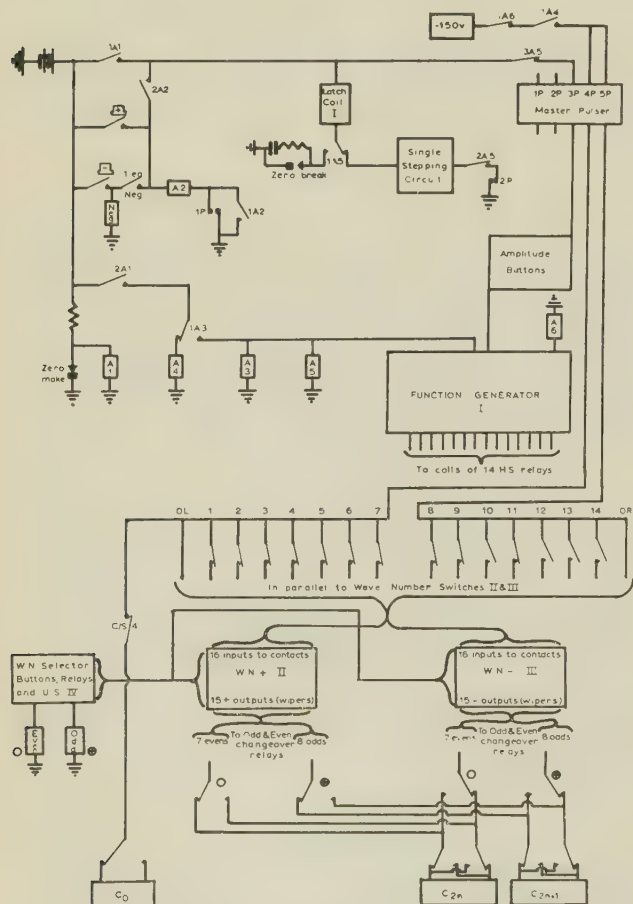


Fig. 2. Schematic circuit diagram.

* Relays are designated by a letter followed by a number. These two alone denote the coil of a relay. A relay contact set designated by a number preceding the letter.

† The circuit for this single stepping operation is No. M1 from A.E.I. (Woolwich) Ltd.

giving an automatic 100 millisecond contact is really desirable and could easily be arranged by means of a lugged relay.

If the start — button is pressed the five relays operating the 31 changeover contacts immediately preceding the counters are energized. The supply goes through one contact on each relay before reaching A2, thus ensuring that the changeover is complete before the uniselector starts. After that the sequence is exactly the same as for the start +.

Table 1. Wiring schedule for the function generator (Uniselector I)

The numbers in the table for arcs 1–12 are wire numbers and the contacts labelled with a given number are connected to the H.S. relay coil of the same number. On arcs 13 and 14 the wires go to the corresponding switches of the tens row of amplitude push buttons, on arc 15 to the units switches (see Fig. 3). Arc 16 is commoned. The rows are numbered according to the indicator dial and arc 1 is nearest to the dial. Wipers 1–14 are single ended and on arcs marked * they operate on the second half of the rotation.

Wipers 1–12 are commoned to the 50 v supply and the connections of wipers 13–15 are shown on Fig. 3. Wiper 16 is utilized in the single stepping circuit.

	ARC NUMBERS															
	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A6
51	0	0	5	-	9	-	-	7	11	-	6	-	8	10	10	
50	9	9	4	9	-	12	7	4	11	11	5	13	-	8	-	
49	8	9	4	-	9	-	-	-	-	-	-	-	-	10	10	
48	7	9	4	-	12	-	-	-	11	11	-	-	8	6	-	
47	6	9	4	9	-	12	-	7	-	11	13	8	-	10	10	
46	5	9	4	-	9	-	7	-	11	-	-	-	6	-	-	
45	4	9	4	9	12	-	-	11	14	13	-	5	8	10	10	
44	3	9	4	-	9	12	-	-	11	-	-	3	-	8	-	
43	2	9	4	-	-	-	-	7	11	11	-	6	5	10	10	
42	1	9	4	9	9	-	12	14	7	11	13	-	4	1	8	
41	0	9	4	-	-	-	-	-	11	-	-	8	6	10	10	
40	9	8	3	9	-	12	-	-	-	11	-	13	-	-	-	
39	8	8	3	-	9	-	12	7	11	-	-	-	8	10	10	
38	7	8	3	9	-	-	7	4	11	11	13	6	-	8	-	
37	6	8	3	-	9	12	-	-	-	11	-	5	-	10	10	
36	5	8	3	-	-	-	-	-	11	13	-	6	-	8	-	
35	4	8	3	9	12	-	14	7	7	11	-	8	5	10	10	
34	3	8	3	-	9	12	-	-	11	-	-	-	-	-	-	
33	2	8	3	9	-	-	-	14	11	11	13	6	8	10	10	
32	1	8	3	-	9	-	12	-	3	11	-	-	8	-	-	
31	0	8	3	-	-	12	7	7	11	13	-	-	10	10	-	
30	9	7	2	9	-	-	4	-	-	11	-	-	6	5	8	
29	8	7	2	-	9	-	12	-	11	-	-	8	-	10	10	
28	7	7	2	9	-	12	-	-	11	11	13	-	5	-	-	
27	6	7	2	-	9	4	-	7	7	11	-	6	8	10	10	
26	5	7	2	-	12	-	-	-	11	13	-	-	8	-	-	
25	4	7	2	9	9	-	-	-	14	11	-	-	6	10	10	
24	3	7	2	12	-	-	-	7	11	-	-	-	2	-	8	
23	2	7	2	9	12	3	7	14	11	11	13	8	-	10	10	
22	1	7	2	-	9	-	-	-	-	-	-	5	-	6	-	
21	0	7	2	9	-	12	-	-	11	11	-	13	8	10	10	
20	9	6	1	-	9	-	-	7	-	11	6	-	5	2	-	
19	8	6	1	-	12	-	7	-	11	-	4	8	-	10	10	
18	7	6	1	9	-	12	-	-	11	11	13	-	-	8	-	
17	6	6	1	-	9	-	-	-	-	-	-	6	-	10	10	
16	5	6	1	9	12	-	14	7	11	11	-	13	-	8	-	
15	4	6	1	12	9	-	-	4	7	11	6	5	8	10	10	
14	3	6	1	-	-	-	-	-	14	11	-	13	-	-	-	
13	2	6	1	9	12	-	-	-	-	11	-	8	5	10	10	
12	1	6	1	-	9	-	-	7	11	13	-	-	3	6	8	
11	0	6	1	9	-	12	7	-	11	11	-	-	-	10	10	
10	9	5	0	-	9	-	12	-	-	11	-	8	-	-	-	
9	8	5	0	9	-	-	11	-	13	-	8	-	6	10	10	
8	7	5	0	-	9	12	-	7	-	11	-	-	-	-	-	
7	6	5	0	-	-	-	7	5	11	13	-	8	4	10	10	
6	5	5	0	9	12	-	14	-	11	11	-	-	8	6	-	
5	4	5	0	-	9	12	-	-	-	11	-	-	5	10	10	
4	3	5	0	9	-	-	-	14	11	7	13	4	6	8	-	
3	2	5	0	-	9	-	12	-	7	11	-	3	8	10	10	
2	1	5	0	-	-	-	-	12	11	13	-	-	-	-	-	
1																A6

4.1.2. The function generator

This generates the function $A \cos 2\pi n/60$ at the sixteen points corresponding to $n = 0-15$. Only 14 H.S. relays (I_1-I_{14}) are required to control the pulses going to 16 counters. This is because the first counter C_0 either gets all the pulses if a cosine of any wave number H is being produced, or none in the case of a sine. A pair (No. 4) of on/off contacts operated by the Cos/Sin switch is all that is required to control this counter. C_{15} registers zero, since it is $A \cos \pi/2$, and however this is redistributed for higher orders it only requires an open circuit and no relay or wiring. By arranging that ten of these relays open when energized and the other four close, it is possible to ensure that no more than six require to be energized at any position of the uniselector, in order to control the pulses going to the counters. The energizing of these relays is accomplished by utilizing six 100 contact switches, provided by taking six pairs of 50 contact arcs* on the uniselector and arranging single-ended wipers in opposition on each pair. The wipers are commoned to the 50 v supply and the coils of those H.S.

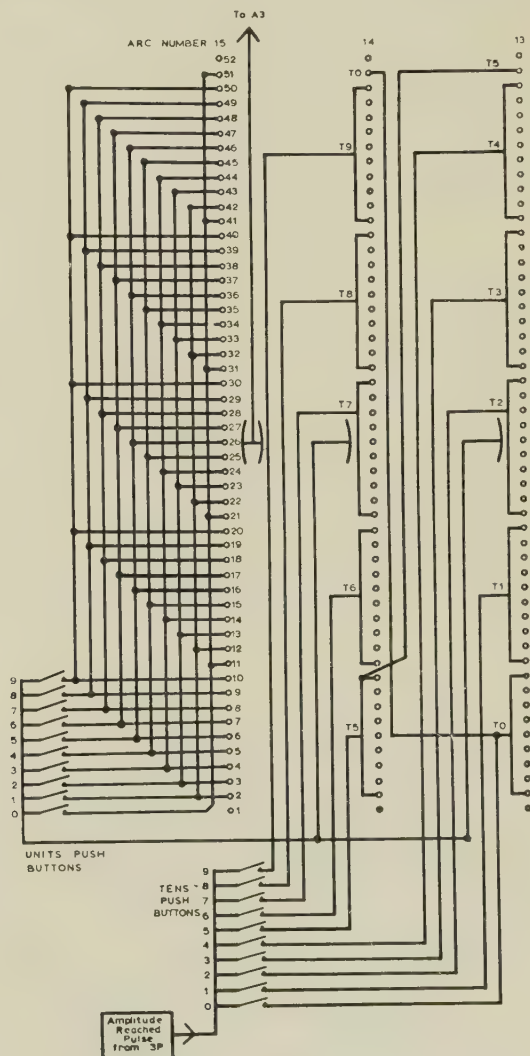


Fig. 3. Amplitude control circuit diagram. The bracketed contacts on arcs 13 and 14 are commoned.

* An arc is a semicircular line of contacts which make connections with one wiper arm of the uniselector as it moves round.

relays requiring to be energized at any position of the unselector are connected to one of the row of 'live' contacts on which the wipers are positioned. Since all 'live' contacts in a row are equivalent there are a large number of possible ways of arranging the wiring. One such way, from which others can be derived, is given in Table 1.

Four arcs of contacts remain unused. Three of these are used for the 'Amplitude Reached' circuit and the wiring connections are also shown in Table 1. The fourth is commoned and used in the single stepping circuit.

The 'Amplitude Reached' circuit is shown in Fig. 3 and requires no comment.

One minor point has to be taken into account. When the unselector is changing over from one single ended wiper to its partner, i.e. from amplitude 50 to 51, there are two rows

of contacts which are not utilized. It would be possible to alter the unselector wiring to obviate this hiatus, but would complicate the amplitude control diagram; this difficulty is easily overcome by the use of A6, energized from two of the contacts on these unused rows. When the unselector wipers reach these rows, 1A6 opens and no pulses can reach the counters.

We now have to deal with the rearrangement of the outlets from the 14 H.S. counters (and the I_0 and I_{15} 'outlets') to produce higher and zero order terms. For the first order $H=1$ cosine term the outlets from relays I_1 – I_{14} go to counters C_1 – C_{14} . C_0 gets all the pulses via the Cos/Sin switch (outlet I_0) and C_{15} gets no pulses (I_{15}). The rearrangement of the outlets is performed by the wave number (W.N.) unselectors and associated circuits.

4.1.3. The wave number circuits

From each outlet contact of one of the H.S. relays (apart from I_0) two wires run in parallel to the two wave number unselectors II and III. The wiring is soldered to the contacts of the first 15 arcs of the unselectors according to the scheme in Table 2. The position of the wipers of II and III is controlled by the H push buttons and the Cos/Sin switch in conjunction with the small unselector IV as shown in Fig. 4. The position of IV is controlled by the H push buttons, since the motor rotates until wipers Nos. 1 and 15 both find 'dead' contacts. 1H1 then opens and breaks the supply to the motor. One of the wipers 3, 4, 5 or 6 will be 'live' depending on the position of the Cos/Sin switch and the H buttons. From the live wiper the supply goes from the contact of IV to one of the contacts on bank 16 of II and to the same number contact on bank 16 of III. The motor of II and III are energized and the wipers hunt round until they find the live contacts. H9 and H10, fed from Nos. 1 and 15 wipers of II and III, then break the motor circuits and the unselectors lock into the specified position.

When the start button has been pressed 3A2 cuts off the supply from II, III and IV, so that the H buttons can be altered without affecting the unselectors. However, changing from H in the range 0–15 to any other range (15–30, 31–45, etc.) or between any two ranges the Odds/Evens relays may change. In such a case it is essential to wait until the previous amplitude has been reached before altering the H buttons. In any change outside the range 0–15 there must be an alteration in the H relays. Although the final result on the Odds/Evens relays will be the same if the alteration is within one of the ranges of 15, there may be transient effects, so that for $H = 16$ upwards the H buttons should only be altered after the previous amplitude has been reached.

Taking as an example the position of the wipers of II and III corresponding to $H = 2$ (Cos), the wiring on the contacts is arranged so that wipers 1–15 of the unselectors (which are connected to counters C_1 – C_{15}) are connected to the outlets of every other relay, 1I2, 1I4, 1I6, etc. At 15 the function changes sign and 1I6 = –1I4, 1I8 = –1I2, etc. The pulses from 1I14, 1I12, etc., therefore go to the negative inputs of the counters from C_8 to C_{14} . This is arranged by having the 15 wiper outlets from II go to the positive inputs of the counters, those from III going to the negative inputs. If a counter has to be pulsed negatively because the function has become negative, the output from the corresponding relay is connected to the contact on III. If the counter is to be pulsed positively the connection is to II. Thus for $H = 2$ the relay outlets 1I2, 1I4, etc., are connected to contacts II which are connected to wipers 1–7 and thus to the position

Table 2. Wiring schedule for the wave number switches (Unselectors II and III)

The numbers in the table for arcs 1–15 are wire numbers and the contacts labelled with a given number are connected to the outlet contact of the H.S. relay of the same number. The unenclosed numbers refer to the positive wave number unselector (II), those boxed in to the negative wave number unselector (III). Wipers 1–15 of II go to the positive inputs of the corresponding counters (via the odds/evens and $+/-$ relays) and wipers 1–15 of III go, in the same way, to the negative inputs. The labelled contacts of arc 16 on both unselectors are connected to the contacts labelled with the same number on unselector IV (see Fig. 4). All wipers are double ended and wiper 16 in each case goes to the coil of the motor control relay (H9 and H10).

ROW NUMBERS	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
37	37	0	-	0	-	0	-	0	-	0	-	0	-	0	-	0
36	36	-	1	13	3	11	5	9	7	7	9	5	11	3	13	1
35	35	0	13	4	9	8	5	12	1	14	3	10	7	6	11	2
34	34	-	3	9	9	3	-	3	9	9	3	-	3	9	9	3
33	33	0	11	8	3	14	5	6	13	2	9	10	1	12	7	4
32	32	-	5	5	-	5	5	-	5	5	-	5	5	-	5	5
31	31	0	9	12	3	6	-	6	3	12	9	0	9	12	3	6
30	30	-	7	1	9	13	5	3	11	11	3	5	13	9	1	7
29	29	0	7	14	9	2	5	12	11	4	3	10	13	6	1	8
28	28	-	9	3	3	9	-	9	3	3	9	-	9	3	3	9
27	27	0	5	10	-	10	5	0	5	10	-	10	5	0	5	10
26	26	-	11	7	3	1	5	9	13	13	9	5	1	3	7	11
25	25	0	3	6	9	12	-	12	9	6	3	0	3	6	9	12
24	24	-	13	11	9	7	5	3	1	1	3	5	7	9	11	13
23	23	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
22	22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	17	-	0	-	0	-	0	-	0	-	0	-	0	-	0	-
16	16	0	14	2	12	4	10	6	8	8	6	10	4	12	2	14
15	15	-	2	11	6	7	10	3	14	1	12	5	8	9	4	13
14	14	0	12	6	6	12	0	12	6	6	12	0	12	6	6	12
13	13	-	4	7	12	1	10	9	2	13	6	5	14	3	8	11
12	12	0	10	10	0	10	10	0	10	10	0	10	10	0	10	10
11	11	-	6	3	12	9	0	9	12	3	6	-	6	3	12	9
10	10	0	8	14	6	2	10	12	4	4	12	10	2	6	14	8
9	9	-	8	1	6	13	10	3	4	11	12	5	2	9	14	7
8	8	0	6	12	12	6	0	6	12	12	6	0	6	12	12	6
7	7	-	10	5	0	5	10	-	10	5	0	5	10	-	10	5
6	6	0	4	8	12	14	10	6	2	2	6	10	14	12	8	4
5	5	-	12	9	6	3	0	3	6	9	12	-	12	9	6	3
4	4	0	2	4	6	8	10	12	14	14	12	10	8	6	4	2
3	3	-	14	13	12	11	10	9	8	7	6	5	4	3	2	1
2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-



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$$\begin{aligned} \sin 2\pi \frac{n}{60}(30 + H) &= \sin 2\pi \left(\frac{n}{2} + \frac{n}{60}H \right) \\ &= \begin{cases} + \sin 2\pi \frac{n}{60}H & \text{for } n \text{ even} \\ - \sin 2\pi \frac{n}{60}H & \text{for } n \text{ odd} \end{cases} \end{aligned}$$

$$\sin 2\pi \frac{n}{60} (60 - H) = \sin 2\pi \left(n - \frac{n}{60} H \right)$$

$$= -\sin 2\pi \frac{n}{60} H \text{ for all } n.$$

For $H = 61-120$ the expressions are the same as for $1-60$. It can thus be seen that values of the function at the points $n/60$ for any wave number can be obtained from the values for $H = 0-15$ by a rearrangement of the signs. This is accomplished by the relays H2 to H8 and the odds and evens relays in conjunction with the H push buttons and the Cos/Sin switch as shown in Fig. 4.

Finally, the function with negative amplitude is obtained by means of 31 changeover relay contacts which are shown schematically in Fig. 2.

4.2. The counters

The circuit for reversible drive dekatrons was supplied by the Tube Technical Services Department of Ericsson's Telephones Ltd., and is shown in Fig. 5. The power supplies

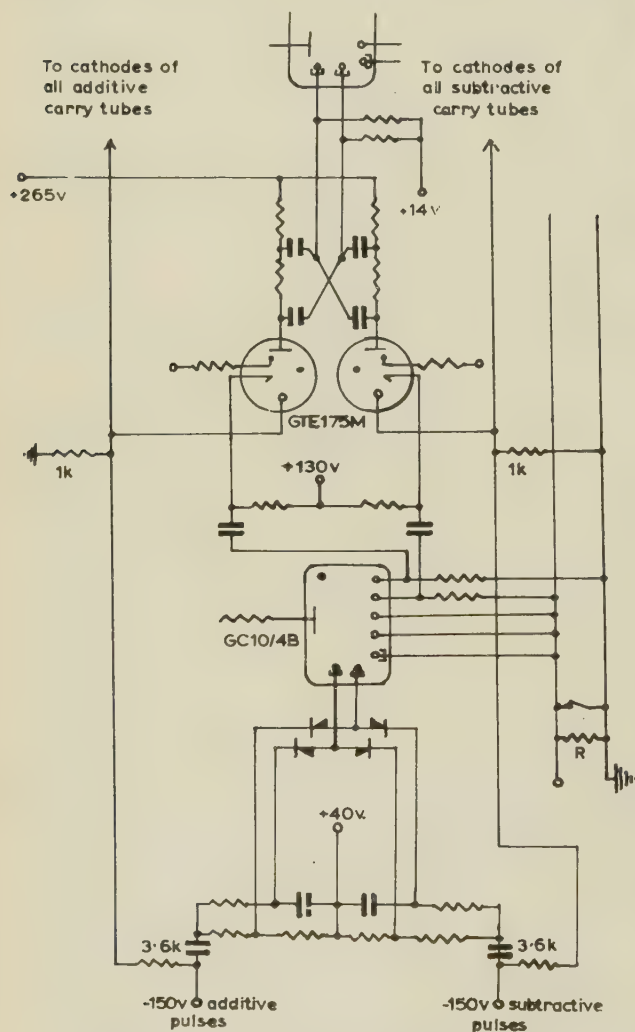


Fig. 5. Dekatron counter circuit diagram. Except where given on the diagram, the component values and voltages are those given for counters in Ericsson's *Electronic Tube Handbook*, circuits LK105 and LK108. The -20 v line is unnecessary for this rate of counting. The value of R is best determined by trial to give a voltage drop of about 100 v when the zeroing switch is opened.

and pulsing lines are carried in a harness with socket ends connecting with the 16 plugs on the counters. Each counter chassis (8 in. $\times$ 3 in. $\times$ 6 in.) is held by two nuts to the front panel and is separately removable for servicing. Sixteen counters with four dekatrons and six carry valves each have been accommodated in a panel 33 in. $\times$ 13 in. and the whole assembly is 6½ in. deep. The panel is hinged at the top of the control desk and can be swung down for servicing, as shown in Fig. 6.

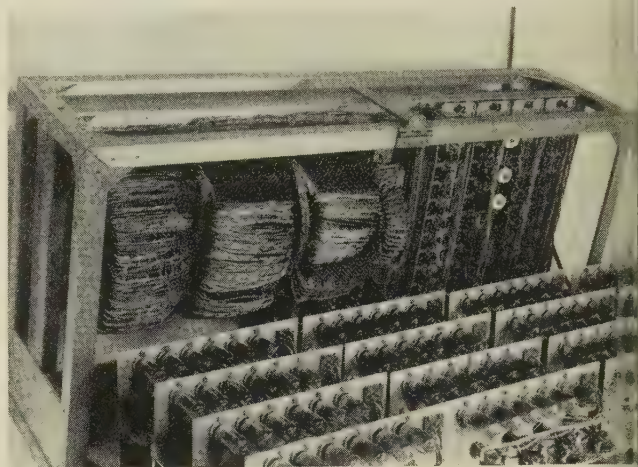


Fig. 6. Photograph of the machine with cover removed and counter panel swung down to show the layout of the Post Office equipment.

4.3. The pulsing unit

The contacts are made up from parts supplied by Autophone Ltd. of London. The time of closure is determined by the size of the cut out segment of the disk cam, in degrees. Contact pair 1P only functions at the start when the button is pressed. Its job is to make sure that the first single stepping pulse for the uniselectors is of full duration. The cam gap is 90° and is positioned so that its contacts close when the motor pulse contacts 2P are open. The gap for 2P is 270°. 3P contacts close to allow the 'amplitude reached' pulse through and the gap is 35°. 4P and 5P are both fed from the -150 v supply and are arranged to share the work of pulsing the counters. The gaps are the same, 50°. The relative positions of the gaps can be given in terms of their leading edges. The number of degrees rotation to bring the various leading edges parallel to that of the 1P cam in its initial position is: 1P: 0°; 2P: 90°; 3P: 80°; 4P and 5P: 35°. It is essential that sufficient time be given to the H.S. relay to settle down when the unselector has stepped on, otherwise there may be sufficient bounce and consequent arcing at the relay contacts to cause some of them to stick. It is also essential that the gap for pulsing the counters should be at least as large as indicated above. The units dekatron can be driven with a very much shorter pulse, but the method of carry-over utilizes the primary pulse as well as that from the carry valve, and reliable carrying could not be achieved with a shorter pulse. The outlet contacts of 4P and 5P are each connected to earth by a 2μ F condenser and 50Ω resistance together with a $5 \text{ k}\Omega$ resistance in parallel. The first contact acts as a spark quench and the latter provides a leak to earth. There are occasions when none of the counters connected to one of the contacts receives a pulse. There is then no means of discharging the smoothing condenser (in the absence of

h a leak) and when the uniselector steps on the discharge sufficient to cause spurious counts.

4.4. The power pack

The Post Office gear has been successfully run from a stabilized 48 v transistorized power pack (Elliott Bros. Ltd., type B.828/776). This gives an average current of 2 amps without overheating and will maintain regulation up to 100 ms for short periods and give pulses of much greater peak current with little voltage drop.

The counter supplies are obtained from a standard cathode ray power type power pack giving unstabilized 475 v for the grids of the dekatrons and a stabilized 265 v, from which bias voltages are obtained by potentiometers. The 100 v supply is obtained from a separate transformer, amplifier and smoothing circuit. The -150 v pulsing supply is obtained from an isolating transformer, a Berco Regavolt transformer, a selenium full wave rectifier and 2000 μ F capacitors.

4.5. Construction

The machine is constructed of four distinct units and a separate power pack.

The Post Office gear is all mounted on the rear frame which can be removed from the base. All connections go to two 34-way connectors, sixteen 2-way connectors, one 12-way and one 8-way connector, on the frame. The pulsing unit is mounted in the bottom of the rear frame, but is easily removed and is connected by the 12-way plug and socket.

The control desk is connected to the rear frame by means of the two 34-way plugs and sockets.

The counter panel pulsing lines are connected to the rear frame by the sixteen 2-way plugs and sockets. The power supply harness ends in a 12-way connector, the socket of which is connected to a 14-way socket on the side of the control desk.

The main power supply (230 v a.c.) is fed into a sunk plug on the side of the desk. All 230 v a.c. for the power pack is carried outward in the same multicore cable that carries the power supplies back to the machine. Each of the three power packs has its own cable, the counter supplies and the 100 v d.c. supply going to the 14-pin socket and 2-pin sunk plug on the desk; the -150 v supply goes to the 8-pin socket on the rear frame.

All plugs and sockets (except for the sixteen 2-way connectors which are numbered) are arranged so that it is impossible to connect them wrongly, and so that only sockets can have contacts.

The power pack cabinet is 28 in. $\times$ 15 in. $\times$ 12 in. and normally go under the table carrying the machine.

Comparison with the original Beevers-Macewan machine

(a) The function generator in the present design controls 16 relays for all the counters instead of acting as a direct multipole switch for some of the counter pulses. Careful selection of the relays to be energized 'on' has reduced the number of control banks needed to six pairs, which enables 'amplitude reached' circuits to be accommodated on the uniselector, doing away with one large and one small auxiliary uniselector required in the original design.

(b) The uniselector steps round using its own motor and a standard P.O. circuit, instead of using an auxiliary motor to drive the uniselector armature through a clutch. The original design rotated at a rate of 50 c/s, but the wipers were never still on the contacts, and contact bounce, which must have been a problem with mechanical counters, would be an almost insuperable obstacle with dekatrons. In the new design the uniselector is locked stationary at each step. This entails a maximum stepping rate of 20 c/s, but the total time taken is not much greater, on average, because the uniselector homes at 200 c/s as soon as the desired amplitude is reached.

(c) The original design provided for automatically altering the wave number as each term was put in. In the new design the W.N. buttons can be altered as soon as the start button is pressed for wave numbers up to 15 so that little would be gained by an inflexible automatic change. The buttons also give a visual indication of the term being added in.

(d) There are other, less important, differences. The pressing of the amplitude buttons also started the machine operating in the original design, but a + or - switch had to be altered first, if the amplitude changed sign. In our design the start button has to be pressed after setting the amplitude keys, but automatically selects the sign as well.

6. Postscript

Just as the dekatron counters were being finished, English Numbering Machines Ltd. developed an electromechanical print-out counter which should be ideal for this machine. Dekatron counters have the disadvantage of being difficult to read and any mistakes made in recording the readings cannot be easily checked. The recording by hand of 16 totals also takes considerable time. These disadvantages would be obviated by print-out counters. Only the impossibility of obtaining such counters, demonstrated by nearly 15 years trials, led to the development of dekatron counters at all. If the new electromechanical counters (which are only half the cost of the dekatron components) prove satisfactory, it is hoped to build a new machine employing them, and to incorporate the additional Post Office equipment required to generate the odd 120ths as well as the even.

7. Acknowledgments

The original circuit diagrams for the P.O. gear, containing the major design modifications, are due to Dr. A. D. Booth.

Acknowledgments to the Paul Fund, Ericsson's Telephones Ltd., and A.E.I. (Woolwich) Ltd. have been made in the text. In the last case, it is a pleasure to acknowledge the patient help of Mr. Edward and Mr. Lang of the Mechanical Development Group. The mechanical construction of the whole apparatus was carried out by the technical staff of this laboratory. From its inception the project has received encouragement and support from Professor J. D. Bernal.

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Use of 'air bleed' when measuring pressure in vacuum processes in which condensable vapours are present

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Abstract

Condensation may occur in a vacuum gauge which is used for measuring the pressure in a vacuum system in which a liquid is being evaporated at elevated temperature and the pressure of the liberated vapour exceeds the saturation pressure of this vapour at the temperature of the vacuum gauge, which is usually at ambient temperature. In this paper, a pressure-measuring method is described which prevents condensation or liquefaction occurring in the manometer or in the line connecting it to a vacuum system. The essence of this method is the reduction of the vapour pressure in the vacuum gauge, or in the pipeline leading to it, by a small stream of air, to a value at which condensation or liquefaction cannot occur. A short note is also added on the use of mercury manometers on 'wet' vacuum systems.

Introduction

MEASUREMENT of vapour pressure frequently requires a more elaborate instrument than is required for measuring permanent-gas pressure. This requirement may arise, for example, because of possible condensation in the vacuum gauge, which may occur in a mercury U-tube manometer or capsule gauge used for measuring the pressure in a vacuum system in which a liquid is being evaporated at elevated temperature and the pressure of the liberated vapour exceeds the saturation pressure of this vapour at the temperature of the vacuum gauge (which is usually at ambient temperature), or it may arise because of liquefaction and therefore, distortion of the pressure reading, which may occur when a McLeod gauge is used for measuring vapour pressure. In this paper, a pressure-measuring method is described which prevents condensation or liquefaction occurring in the vacuum gauge.

The essence of the vapour-pressure measuring method described below is the reduction of the vapour pressure at the manometer point by a small bleed of air to a value at which condensation or liquefaction cannot occur. This is readily achieved by connecting the manometer to a tube, one end of which is open to the vacuum system where the pressure is to be measured. The other end is provided with an air-admission valve through which a small stream of air is admitted to prevent vapours from the vacuum system diffusing towards the manometer. Although this method is not new in vacuum technique (Gaede 1950), a quantitative treatment of it has not been fully dealt with. The formula derived in this paper is similar to that relating to one gas diffusing through another stagnant gas, but is derived and presented in a manner rendering it directly applicable to this 'air-bleed' pressure-measuring method.

This method is applicable for measuring the pressure in vacuum systems in which there is a mixture of gas and vapour or a single vapour. The derivation of the formula is not exact in that the temperature of the diffusing fluids is assumed constant and the simple gas law is applied. For practical use, however, for which this method is intended, this treatment is adequate, as is illustrated by an example in the text and verified by experiment.

Derivation of formula

In Fig. 1, V is a volume representing a vacuum system in which the partial vapour pressure is p_{v2} and partial air pressure p_{a2} . To this volume, a tube of diameter d is connected. A small leak of air is admitted into the tube to reduce the partial vapour pressure at the manometer point to the desired value, say p_{v1} .

According to Fick's law, the rate of mass flow of vapour w_v (or any other fluid) by diffusion per unit area is given by

$$w_v = -D \frac{dp_v}{dx} \quad (1)$$

where D is the diffusion coefficient of the vapour under consideration through air, and ρ_v is the density of the vapour at point x . Using the simple gas law, which holds approximately for low pressures,

$$\rho_v = \frac{p_v}{R_v T} \quad (2)$$

where p_v is the partial vapour pressure at x , R_v the gas constant for the vapour in question and T the absolute temperature (assumed constant).

Differentiating Eqn (2) and substituting into Eqn (1),

$$w_v = -\frac{D}{R_v T} \frac{dp_v}{dx} \quad (3)$$

The assumption is made that the air stream is so small that there is negligible pressure drop due to flow and that the total pressure along the tube is constant.

Since the partial pressures of air p_a and of vapour p_v at any point along the tube add up to the total pressure p which is constant along the tube, there corresponds to a gradient of the partial vapour pressure a gradient of the partial air pressure (see the pressure distribution diagram, Fig. 1).

Equation (3) for air, representing the rate of mass flow of air per unit area by diffusion in the opposite direction to the vapour flow, is given by

$$w_a = -\frac{D}{R_a T} \frac{dp_a}{dx} \quad (4)$$

where the suffix a refers to air. Superimposed on the mass transfer by diffusion is the mass transfer due to the stream

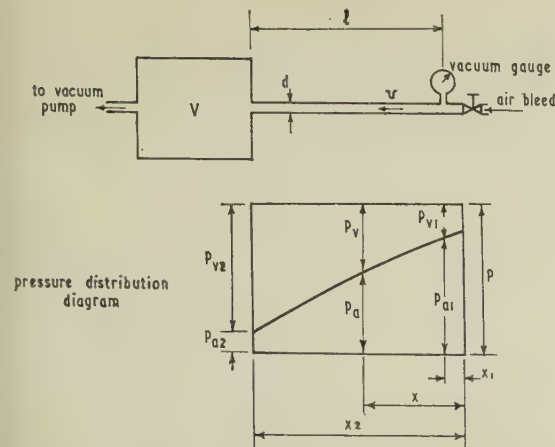


Fig. 1. Diagram for derivation of air-bleed formula.

admitted. Let the velocity of flow in the tube, caused by stream of air, be v . The amount of vapour transported through this flow through the tube section at x per unit area and time is

$$v\rho_v = v \frac{p_v}{R_v T}$$

and the net rate of vapour flow per unit area at x is

$$w_v = - \frac{D}{R_v T} \frac{dp_v}{dx} + v \frac{p_v}{R_v T} \quad (5)$$

The same relation must be valid for the net rate of air flow; therefore

$$w_a = - \frac{D}{R_a T} \frac{dp_a}{dx} + v \frac{p_a}{R_a T} \quad (6)$$

To prevent vapour diffusing towards the manometer, the net flow of vapour in the tube against the air stream must be zero. Equating expression (5) to zero, the flow velocity due to the stream of air is

$$v = \frac{D}{p_v} \frac{dp_v}{dx} \quad (7)$$

Therefore the total pressure is given by

$$p = p_v + p_a = \text{constant}, \quad (8)$$

$$\frac{dp_v}{dx} = - \frac{dp_a}{dx} \quad (9)$$

From Eqns (6), (7), (8) and (9)

$$\frac{dp_v}{p_v} = \frac{w_a R_a T}{D p} dx \quad (10)$$

Integrating Eqn (10) between x_1 and x_2 ,

$$\ln \left(\frac{p_{v1}}{p_{v2}} \right) = \frac{w_a R_a T}{D p} (x_1 - x_2), \quad (11)$$

that is,

$$\ln \left(\frac{p_{v1}}{p_{v2}} \right) = - \frac{w_a R_a T}{D p} l, \quad (12)$$

where l is the length of tube to the manometer point. But

$$w_a = \frac{\text{mass of air admitted per unit time}}{\text{cross-sectional area of tube}} = \frac{W_a}{\frac{1}{4} \pi d^2}$$

Substituting the above value for w_a ,

$$\ln \left(\frac{p_{v1}}{p_{v2}} \right) = - \frac{4 W_a R_a T l}{\pi d^2 D p} \quad (13)$$

In vacuum practice, the product $W_a R_a T$ is denoted as the throughput Q_a , which is the quantity of air (or vapour) passing a given section of a pump or pipeline in unit time, and is measured as the product of the partial air pressure p_a and its volume per unit time S_a at the pressure at that section. Eqn (13) can, therefore, be written in the following form:

$$\ln \left(\frac{p_{v1}}{p_{v2}} \right) = - \frac{4 Q_a l}{\pi d^2 D p} \quad (14)$$

With Eqn (14) it is possible to calculate the amount Q_a of air to be admitted to reduce the partial vapour pressure from p_{v2} in the vacuum vessel to the desired low value p_{v1} at the manometer when this is connected to a tube of length l and diameter d , or, vice versa, for an assumed air bleed and tube diameter, the tube length can be determined.

Example of use

To illustrate the use of Eqn (14), consider the following example:

On a certain concentration or drying process from which water is extracted in the form of vapour (by heating the processed material under vacuum and by pumping the vapour that is liberated) it is intended to measure the pressure, which initially is in the region of 50 torr, by means of a capsule vacuum gauge. The design of the gauge, which is barometrically compensated, exposes its working and indicating parts to the atmosphere prevailing in the vacuum system.

To avoid condensation in the capsule gauge, the air-bleed method is used. It is assumed that the partial water-vapour pressure at the manometer point (which must be below saturation at ambient temperature in order to prevent condensation) should be not higher than 10 torr. If it is also assumed that the effective speed of the vacuum pump used on this process is 50 litres per minute, and that the partial air-pressure rise in the vacuum system due to the air bleed should amount to not more than 0.02 torr, then the quantity $Q_a = 50 \times 0.02 = 1$ litre-torr per minute is obtained. The problem is to determine the length of tube (of say 1 cm diameter) that will reduce the partial vapour pressure from 50 to 10 torr.

It is assumed that the total pressure in the vacuum system is equal to the partial water-vapour pressure, other partial pressures being negligible. The diffusion coefficient for water vapour in air is determined from the following equation*

$$D = \frac{1.46 \times 10^{-4}}{p} \frac{T^{5/2}}{T + 441} \text{ ft}^2/\text{hr} \quad (15)$$

where T is the absolute temperature ($^{\circ}\text{R}$ on the Fahrenheit scale) and p is the total pressure (atm.). Substituting values for T and p (542 $^{\circ}\text{R}$ † and 50/760 atm. respectively), the diffusion coefficient D equals 15 ft²/hr or 231 cm²/min. Rearrangement of Eqn (14) gives

$$l = - \frac{\pi d^2 D p}{4 Q_a} \ln \left(\frac{p_{v1}}{p_{v2}} \right)$$

* The equation is given by J. D. Spalding, S.B., *Thesis in chemical engineering*, M.I.T. 1946.

† For the temperature inside the tube, an average value is taken between that prevailing inside the vacuum chamber (read from the saturation vapour pressure curve for 50 torr) and the ambient temperature which is assumed to be 524 $^{\circ}\text{R}$ or 18 $^{\circ}\text{C}$.

and substitution of numerical values gives

$$l = -\frac{\pi \times 1 \times 231 \times 50}{4 \times 1 \times 10^3} \ln \left(\frac{10}{50} \right) \frac{\text{cm}^2 \times (\text{cm}^2/\text{min}) \times \text{torr}}{\text{cm}^3 \times \text{torr}/\text{min}},$$

so that l is 14.5 cm for the 1 cm diameter tube stipulated.

As can be seen from the above example, the required length of tube is short and the assumed pressure rise caused by the air stream is negligible compared with the total pressure of 50 torr.

Notes on the application and limitation of the air-bleed method

In practice, since some of the assumed values and the diffusion coefficient may only be predicted or estimated approximately, an allowance should be made by increasing the length of tube or, alternatively, by increasing the air bleed or by reducing the tube diameter. If the length l is adjusted in order to ensure absence of condensation, the pressure reading will remain virtually unaltered. For instance, if, in the above example, the calculated length of the tube is doubled, the only increase in the pressure reading is the doubled pressure drop along the tube caused by the admitted stream of air. But, according to Eqn (16), given below, this pressure drop is less than 10^{-3} torr, which is quite negligible compared with the measured pressure of 50 torr. It is apparent that the practical application of Eqn (14) does not involve great accuracy because, as shown above, the pressure reading is hardly influenced if the estimated parameters l , d and Q are somewhat adjusted. What is important is to choose the parameters so as to ensure absence of condensation or liquefaction with a minimum or a tolerable distortion of the pressure reading.

The quantity of air to be admitted can be measured with a pipette or, if the effective pumping speed of the vacuum pump is known, by adjusting the air admission valve till the assumed (or a tolerable) rise of pressure is observed on the vacuum gauge. The length of tube in which the partial vapour pressure may exceed saturation at ambient temperature should preferably extend into the vacuum system in order to avoid condensation anywhere in the gauge line, and also slope away from the vacuum gauge so as to prevent accumulation of condensate in case condensation does occur.

The pressure differential Δp along the tube caused by the admitted stream of air is given by

$$\Delta p = \frac{128 \mu Q a}{\pi d^4 p} \quad (16)$$

where μ is the coefficient of viscosity.

To keep the pressure drop low, the diameter d should not be very small, although reduction of the diameter greatly affects the vapour pressure ratio in Eqn (14).

The air bleed increases the true reading of the pressure that is being measured by Q/S . Therefore, at low pressures and when the pumping speed S of the vacuum pump is low, the air bleed should be kept small and the length and diameter of the tube so chosen as to obtain the required vapour-pressure drop in the tube.

Some vacuum gauges, for example the Pirani gauge, are normally calibrated for air, and when used for other gases or vapours, may give grossly distorted readings, especially at pressures above 0.2 torr. The air-bleed method can in this instance be used to replace the vapour or gas in the gauge head by air and give a truer pressure indication.

If the McLeod gauge is used for vapour pressure measurement, the partial vapour pressure (p_{v1}) at the gauge point of the tube must be reduced to such a low level that liquefaction

cannot occur when the pressure reading is taken and the air-vapour mixture is compressed.

If V is the volume of the McLeod gauge between points A and B (see Fig. 2), a the cross-sectional area of the tube

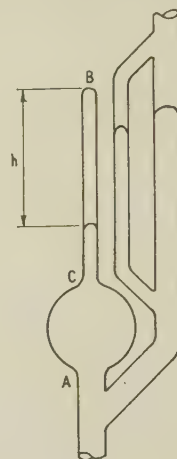


Fig. 2. McLeod gauge.

CB, p_{vs} the saturation vapour pressure corresponding to ambient temperature and h the length of tube into which the air-vapour mixture is compressed, then, to avoid liquefaction in the McLeod gauge the following inequality, which is based on Boyle's law, must be fulfilled:

$$p_{v1} < \frac{a}{V} h p_{vs} \quad (17)$$

When the pressure rise in the vacuum system, or pressure drop along the tube, caused by the admitted stream of air is not small compared with the pressure actually measured, the air-bleed method cannot be relied upon and, therefore, it is advisable to estimate these pressure differentials for each particular application. The pressure rise in the system caused by the air bleed, is obtained by dividing the amount of air admitted (expressed by Q) by the effective speed of the vacuum pump. The pressure drop along the tube to which the manometer is connected is obtained using Eqn (16). In most cases, these pressure differentials can be reduced or eliminated by discontinuing the air bleed while the pressure reading is being taken. At low pressure, when the transition region of flow is approached and inter-molecular collisions become fewer, this air-bleed method will be ineffective.

Experimental verification

Simple tests were carried out to find to what extent calculated values, obtained with Eqn (14), differed from quantities determined experimentally. With the technique described below, the discrepancy was found to be about 10%.

The apparatus used is shown in Fig. 3. An oil-sealed

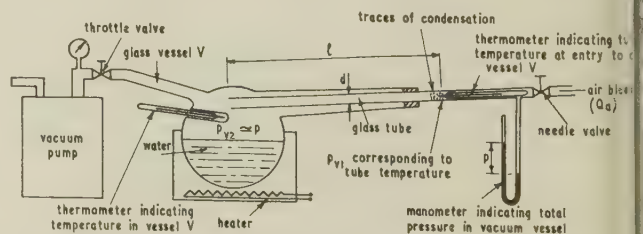


Fig. 3. Apparatus used for experimental verification.

ary pump with gas ballast was used to maintain a negligible partial air pressure in the glass vessel V in which water vapour was generated. A glass tube of known diameter was partly inserted into the vessel to eliminate condensation in the tube, which would distort results. At the other end of the tube was connected a mercury manometer to measure the total pressure in the vessel, and a needle valve for admitting air. The rate of air admittance was measured with a pipette. A thermometer was fixed to the glass tube indicating the temperature of the tube near its entry into the vessel V. The air bleed was adjusted until traces of condensation were observed, maintained, and confined close to this point.

Having maintained approximately steady conditions for a number of hours, and observed that condensation did not progress or recede along the tube, readings were taken of the quantity of air admitted Q_a , total pressure p , temperature in the glass vessel V, tube temperature near entry into vessel V and length of tube l to the point where traces of condensation were maintained. The partial water-vapour pressure at this point was read from the saturation vapour pressure curve corresponding to the tube temperature near its entry into vessel V.

For the temperature inside the tube within the glass vessel a mean value was taken between that inside the vessel and that measured at the tube entry into it. The above listed readings are shown in the Table in which the measured length is also compared with the calculated value.

Table of experimental results

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
96	49	37.6	207	20.5	18.1	29	32.7
96	40	34.4	209	21	18.6	29	30.6
99	34.5	31.5	1086	19.1	16.5	27.5	28.2
5	36.5	32.6	433	20.3	17.8	32	34.7
5	74	45.5	894	20.5	18.1	29	34.2

Glass tube diameter d (cm); (2) total pressure p (torr) $\approx$ partial water vapour pressure p_{v2} in vessel V; (3) temperature in vessel V ($^{\circ}\text{C}$); (4) quantity of air admitted per unit time Q_a (ml $\times$ torr/min); (5) temperature of glass tube at point of condensation near entry into vessel V ($^{\circ}\text{C}$); (6) partial water vapour pressure p_{v1} (torr) corresponding to tube temperature at point of condensation; (7) measured length l (cm) to point of condensation; (8) calculated length l (cm) using values in columns (1) to (6).

Note on the use of the mercury U-tube manometer on 'wet' vacuum systems

Users of mercury U-tube manometers on 'wet' vacuum systems, in which vapours are liberated in large quantities, find that the mercury column breaks up and mercury is lost from the manometer when the system is being evacuated. This failure of the mercury U-tube manometer on wet systems is caused by condensation on its walls and on the mercury itself. Condensation may occur if the vapour pressure in the vacuum system is above the saturation pressure corresponding to ambient temperature, or it may also occur

while the system is being brought to atmospheric pressure, even though the vapour during the actual process is below saturation. While opening the system to atmospheric pressure, vapour that is present in the line leading to the manometer and in the manometer itself is compressed and liquefied by rising pressure. When re-evacuating the system, the mercury column may sweep over the liquefied vapour and mix with it before it can completely re-evaporate. During the subsequent, final stages of evacuation, when a low pressure is reached, the liquid mixed with the mercury evaporates, breaking up the mercury column. To avoid condensation in the manometer, when opening the vacuum system to atmosphere, it should be isolated beforehand.

Figure 4 shows a mercury manometer suitable for vapour

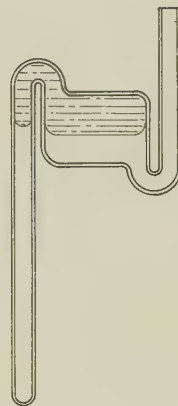


Fig. 4. Mercury manometer for vapour-pressure measurement.

pressure measurement. The level in the mercury reservoir changes very little with pressure variation and vapour that may condense and accumulate on its surface does not freely mix with the mercury if the manometer is kept in a vertical position. The design allows only a small amount of condensate to accumulate on the mercury surface, so that it does not add a large pressure head and distort the reading. Correction can easily be made for the condensate head if greater accuracy is required.

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Correction term for dielectric measurements with cavity resonators*

by E. S. HOTSTON, Ph.D., A.Inst.P., College of Technology, Birmingham†

MS. received 27th September 1960

Abstract

The effect of varying the diameter of a polystyrene disk on the value of its dielectric constant when measured in a resonator of fixed diameter is investigated. Agreement is obtained with results predicted by perturbation theory.

THE use of a right circular cylinder excited in the H_{01n} mode of resonance to measure the dielectric properties of low loss insulating materials at microwave frequencies is well known (Horner *et al.* 1946, Barlow and Cullen 1950, Jackson *et al.* 1946).

Figure 1 shows a section of such a cavity resonator, the walls are perfect electrical conductors, the axis of symmetry is taken as the z axis. The region $0 < z < l_1$ is usually filled with air, and the region $l_1 < z < l_1 + l_2$ contains the material under test. If a solid dielectric is being investigated it is usually machined into the shape of a parallel-sided disk. This gives rise to a possible source of error, since the disk must move freely in the resonator, and a clearance must be left between the sides of the disk and the wall of the resonator. The amount of clearance permitted before the error in the dielectric constant becomes serious is uncertain.

Figure 2 shows a section of the resonator with a dielectric disk of smaller diameter than the resonator placed centrally at one end of the resonator. The annular space between the disk and the walls of the cavity will be called the gap, it has a volume $\Delta V = \pi l_2(a^2 - b^2)$ where a, b are the radii of the resonator and disk.

A possible means of estimating the change in resonant frequency of the cavity due to the presence of the gap is to use a result due to perturbation theory (see appendix). If f, f_a are the resonant frequencies of the cavities of Figs 2 and 1, respectively, then

$$f^2 = f_a^2 \left\{ 1 + \frac{\int_{\Delta V} (\epsilon_2 - \epsilon_1) \mathbf{E}_2^2 dv}{\int \epsilon \mathbf{E}^2 dv} \right\} \quad (1)$$

where the integral in the denominator of Eqn (1) is taken over the whole volume of the resonator. The notation is such that $\mathbf{E}$ is a real function independent of time which gives the space dependence of the electric field for the unperturbed cavity of Fig. 1, ϵ_1, ϵ_2 are the permittivities of the materials filling the cavity, ϵ_1 applying to the region $0 < z < l_1$ and ϵ_2 to the region $l_1 < z < l_1 + l_2$. Because of the discontinuity that exists at $z = l_1$ $\mathbf{E}$ takes the value $\mathbf{E}_1$ for $0 < z < l_1$ and $\mathbf{E}_2$ in the remainder of the cavity, the two

functions being matched for continuity at $z = l_1$ as well as satisfying the necessary boundary conditions at the walls of the cavity.

An experimental check on the range of validity of Eqn (1) has been made. The cavity used was of variable length, a movable piston forming one of the plane ends. The cavity was arranged with its axis vertical and the dielectric disk placed on the piston which formed the lower plane face

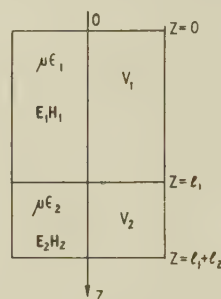


Fig. 1. Section through resonator showing notation.

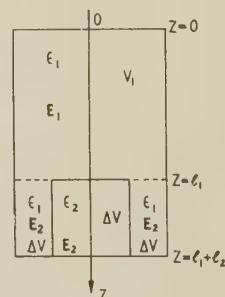


Fig. 2. Section through perturbed resonator showing notation.

Power was fed into the cavity from a microwave oscillator through small holes in the walls, the dimension l_1 of the cavity was varied until resonance was obtained; when this occurred the dielectric constant of the disk could be calculated from the dimensions of the resonator and the frequency of the oscillator.

The cavity was of brass 1.855 in. in diameter, and except for a slightly modified coupling system resembled that described by Hotston and Houldin (1955). A disk of polystyrene cut from a $\frac{1}{4}$ in. sheet and of diameter 1.850 in. was found to have a dielectric constant of 2.56. When this value was checked using the cavity of diameter 1.866 in. as in that paper it was found to be unchanged. A set of disks of varying diameter cut from the same $\frac{1}{4}$ in. sheet of poly-

* This note includes material submitted for the degree of Doctor of Philosophy in the University of London.

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were now placed in the resonator in succession and the dielectric constant measured. The disks were located centrally in the resonator by means of a pin 0.3 mm diameter 4 mm high placed centrally in the face of the piston and making a small hole in the lower face of the disk. Measurements with a separate disk of polystyrene showed that the presence of the hole and pin had no effect on the dielectric constant. The measured values of dielectric constant are given in the Table.

The presence of the gap causes the length of l_1 at resonance to become greater, l'_1 , and the value of dielectric constant of the disk appears to fall. The resonant frequency of a resonator with no gap but with a length l'_1 may be estimated from Eqn (1). Using this estimated frequency a value of dielectric constant of the disk may be calculated since l'_1 , l_2 and the radius of the resonator are known. The nearness of the corrected value of dielectric constant to the true value 2.56 gives an indication of the range of validity of Eqn (1). Results of the calculation are given in the Table.

Acknowledgments

Acknowledgments are due to Dr. J. E. Houldin for advice in the design of the apparatus, and to the Board of Admiralty for financial assistance.

Appendix

The perturbation formula may be derived using a method similar to that of Grivet (1944). With the notation defined earlier the theorem of equipartition of energy may be written

$$\int \mu \mathbf{H}^2 dv = \int \epsilon \mathbf{E}^2 dv \quad (\text{A1})$$

the integrals being taken over the whole volume of the cavity. The permeability μ will be considered as independent of position. Since the space dependence of the magnetic field which is given by $\mathbf{H}$ is related to $\mathbf{E}$ by

$$\text{curl } \mathbf{E} = -j2\pi f \mu \mathbf{H} \quad (\text{A2})$$

Eqn (A1) may be re-written as

$$4\pi^2 f^2 \int \epsilon \mathbf{E}^2 dv = -\frac{1}{\mu} \int [\text{curl } \mathbf{E}]^2 dv. \quad (\text{A3})$$

This equation is to be applied to the cavity of Fig. 2 an approximation to the space dependence of the electric fields in the cavity is required. The simplest assumption is to put $\mathbf{E} = \mathbf{E}_a$ where $\mathbf{E}_a$ is the solution for the unperturbed cavity (Fig. 1). This function $\mathbf{E}_a$ satisfies the correct boundary conditions at the conducting wall of the cavity, and is also continuous at the boundary of the dielectric since it is

reasonable to suppose that circular symmetry exists in the cavity of Fig. 2. $\text{Curl } \mathbf{E}_a$ is also continuous throughout the cavity.

Substituting this value of $\mathbf{E}$ into Eqn (A3) and putting

$$\text{curl } \mathbf{E}_a = j2\pi f_a \mu \mathbf{H}_a$$

we have,

$$f^2 \left(\int_{v_1} \epsilon_1 \mathbf{E}_{a1}^2 dv + \int_{v_2 - \Delta v} \epsilon_2 \mathbf{E}_{a2}^2 dv + \int_{\Delta v} \epsilon_1 \mathbf{E}_{a2}^2 dv \right) = f_a^2 \left(\int_{v_1} \mu \mathbf{H}_{a1}^2 dv + \int_{v_2 - \Delta v} \mu \mathbf{H}_{a2}^2 dv + \int_{\Delta v} \mu \mathbf{H}_{a2}^2 dv \right) \quad (\text{A4})$$

whence

$$f^2 \left\{ \int \epsilon \mathbf{E}_a^2 dv + \int_{\Delta v} (\epsilon_1 - \epsilon_2) \mathbf{E}_{a2}^2 dv \right\} = f_a^2 \int \mu \mathbf{H}_a^2 dv = f_a^2 \int \epsilon \mathbf{E}_a^2 dv \quad (\text{A5})$$

the integral over the whole volume of the cavity being taken over the unperturbed cavity.

Equation (A5) may be written

$$f^2 = f_a^2 \left\{ 1 + \frac{\int_{\Delta v} (\epsilon_2 - \epsilon_1) \mathbf{E}_{a2}^2 dv}{\int \epsilon \mathbf{E}_a^2 dv} \right\}.$$

Values of apparent dielectric constant for polystyrene disks of varying diameters

Diameter of disk (in.)	Clearance with resonator wall (in.)	Dielectric constant		Frequency deviation $f^2/f_a^2 - 1$
		Apparent	Corrected	
1.850	0.018	2.56		
1.700	0.093	2.56	2.56	1.1×10^{-3}
1.600	0.143	2.52	2.55	3.3×10^{-3}
1.500	0.193	2.45	2.49	7.5×10^{-3}

Electrical length of 1.850 in. disk = 1.69 radian; frequency 9600 Mc/s; frequency deviations calculated for $n = 1$ mode of the cavity.

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Vacuum sluice valve of large aperture

by P. H. LISSBERGER, B.Sc., Ph.D., Research Department, Associated Electrical Industries (Manchester) Ltd., Trafford Park, Manchester, 17

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THE sluice valve described here is used in a kinetic vacuum system for the purpose of isolating the pumping unit (combination of 6 in. diffusion pump and liquid-nitrogen trap) from the working space. It could, however, be used wherever a valve of relatively large conductance is essential.

In this type of valve, the sluice plate can be moved relative to the pumping aperture either by translation (Wahl *et al.* 1952, Asao and Muramatsu 1953) or by rotation (Smith and Seagondollar 1952). The latter method was chosen for the following reasons: (i) the actuating mechanism is inherently simple and therefore not susceptible to failure; (ii) the parts can have a high degree of circular geometry, mainly about the axis of rotation of the sluice plate. This allows the parts to be conveniently machined. On the other hand, the surface area of a valve designed on this basis is greater, in principle, by 50% than that of a valve of the same aperture in which the plate is translated. It is, of course, possible to design a valve in which the sluice plate is rotated but where the plate consists of a segment of a circle only. Whilst such a valve would be smaller than the corresponding valve of the type described here, the machining of its parts would be more complicated because its shape (for minimum size) is not circular.

The construction of the 6 in. aperture valve is shown in the Figure, which is self-explanatory. However, the following additional details are important:

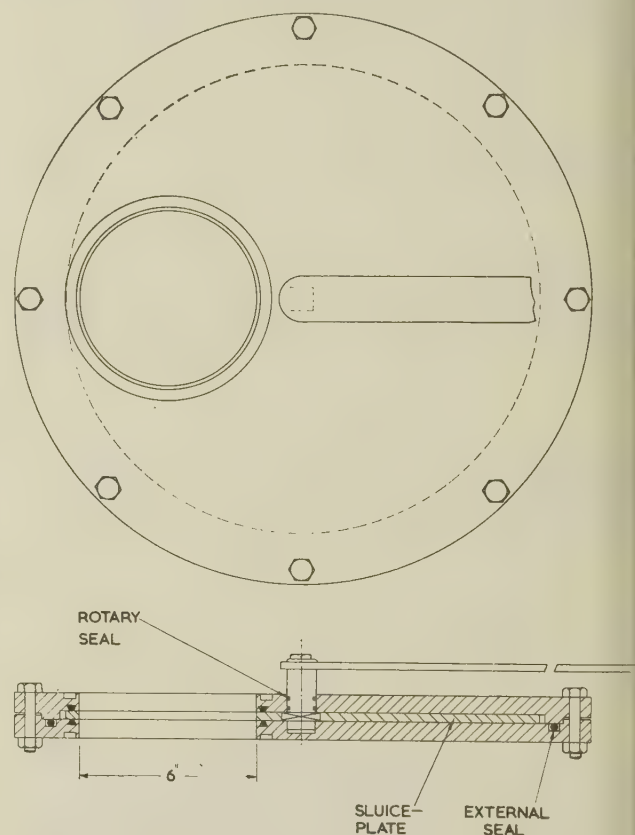
(i) The inner seals and the rotary seals were originally designed to standard specifications but the movement of the sluice plate was then extremely stiff. The grooves were therefore enlarged by small increments until the operation was satisfactory.

(ii) The surface finish on the sluice plate is good ($10\ \mu\text{in.}$) and the edge rounded to allow it to pass smoothly between the inner seals.

The valve has been in operation since January 1959 and no difficulties have been encountered. With the sluice plate lightly greased, the torque required to open or close the valve in 55 s is 35 lb wt ft, i.e. an effort of 15 lb wt on a 28 in. handle. The valve could thus be operated by a small reversible electric motor driving a worm and gear, the latter replacing the handle. The vacuum grease on the sluice plate is not a source of detectable contamination because, when the valve is completely open, the sluice plate lies almost entirely in the body of the valve, which is then isolated from the working space.

As the valve is closed, the gas, which has accumulated in the body of the valve due to small unavoidable leaks, is released into the working space. The amount of this gas is very small; after a period of four hours with the valve in the open position, the gas released by a slight rotation of the sluice plate causes the pressure in the working space to rise momentarily from 2×10^{-6} mm Hg to 2×10^{-4} mm Hg. The pressure returns to a value of 3×10^{-6} mm Hg within

30 seconds. Since the volume of the working space approximately 50 litres, the rate of leakage of gas into the body of the valve is of the order of $10^{-3}\ \mu\text{l/s}$, and this is small fraction only of the rate of removal of gas by the



Plan and section of 6 in. sluice valve.

pumps ($\sim 1\ \mu\text{l/s}$ at 10^{-6} mm Hg). The valve could thus be designed so that the body is being pumped continuously when the plate is in the open position. There would then be no pressure surge when the valve is being closed. On the other hand, the working space would not be isolated from the grease on the sluice plate.

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Simple millimicrosecond pulse generator

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received 9th November 1960

Abstract

This paper describes a hydrogen discharge pulse generator, and gives an application of it to nuclear scintillation counter techniques.

THE purpose of this paper is to draw attention to the properties of the electrical pulse derived from a hydrogen spark discharge and its use in nuclear scintillation counter technique. The characteristics of the light flash from such a discharge have been described elsewhere (Malmberg 1957). This device has several advantages over a mercury relay pulser (De Benedetti and Findley 1958) in that it has a simpler construction, a higher pulse repetition rate and is capable of giving greater pulse amplitude. The arrangement of the pulse generator is shown in Fig. 1. The tube itself consists of a Pyrex envelope with short (of the order of 1 cm) tungsten electrodes of 2 mm diameter, tapered to smooth points at the tips. The tube was outgassed and filled with clean dry hydrogen gas. In operation the capacitor C is charged through the high resistance R until the spark strikes and an electrical pulse is formed across the load resistance R_L . The pulse height is controlled by the electrode gap, the capacitance C and the gas pressure. Generally the capacitance, which was of the order of 2 pF, was varied. Tests were made with electrode gaps from 0.5 mm to 2 mm and gas pressures in the range 20 cm to 76 cm. The striking voltage of the tube, which depends mainly on the two criteria, varied from 500 v to 2000 v and output pulse heights from 20 v to 400 v were observed.

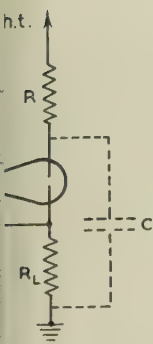


Fig. 1. Hydrogen discharge pulse generator.

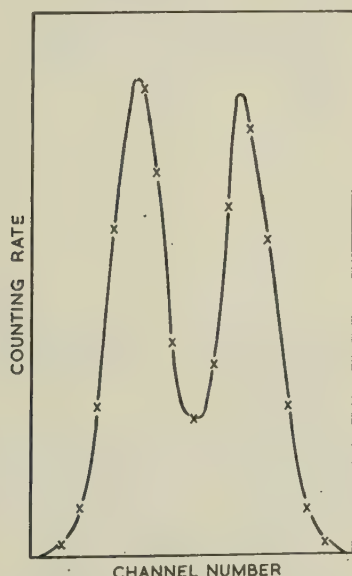


Fig. 2. Kicksorter display. The separation between the peaks corresponds to 5×10^{-10} s.

The pulse shape was determined by applying it directly to the deflection plates of a Tektronix type 517 A oscilloscope. The fastest horizontal sweep of this oscilloscope is 5 $\mu\text{s}/\text{cm}$, and with this the pulse was observed to rise in 1 μs and fall to 10% of its maximum height in 2 μs . The full width at half height of the pulse was 1.5 μs . It is reasonable to assume, taking account of the finite rise time of the deflecting plate circuit, that the actual pulse width and rise time are shorter than the above value.

The repetition rate can be altered by varying the applied voltage or the resistance R which was generally of the order of 30 M Ω . Repetition rates up to 80 kc/s were readily obtained with less than 5% time or pulse height jitter.

One very important factor is the purity of the hydrogen gas. The results quoted here were obtained using hydrogen evaporated from a Dewar flask containing liquid hydrogen. Inferior results were obtained with gas fillings from commercial hydrogen cylinders.

One of the applications of this pulse generator is the determination of the resolving time of a scintillation counter and the associated coincidence unit. The main advantage of this method of initial calibration is that it utilizes pulses of uniform height, and this gives an estimate of the optimum value of the resolving time.

In a typical calibration an R.C.A. type 6810 phototube was set to view the light flash from the spark discharge. The electrical pulses from the phototube and discharge were shaped to square pulses 1.5 v high and of 2.5×10^{-8} s duration, which were applied to a 6BN6 type time-to-pulse height converter (Green and Bell 1958). The output of this unit, which is proportional to the time of overlap of the two pulses, was presented to a hundred-channel kicksorter. By changing the position of the lamp, the kicksorter scale may be calibrated directly against the velocity of light. In the display shown in Fig. 2, the two peaks correspond to a movement of 16.6 cm, i.e. a time difference of 5×10^{-10} s. It can be seen that the resolving time (full width at half height), of this arrangement is 2×10^{-10} s.

It will be noted that this method of calibration can also determine the electron transit time of the photomultiplier, by finding the delay required to bring the pulse from the discharge into absolute coincidence with the output pulse from the photomultiplier.

Acknowledgments

We are indebted to Professor P. I. Dee for his helpful interest in this work.

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A versatile metal to dielectric seal*

by P. C. CONDER, H. FOSTER and H. A. H. BOOT, Services Electronics Research Laboratory, Baldock, Herts.

MS. received 26th October 1960

Abstract

A bakeable vacuum window seal suitable for use as an optical window or as a radio-frequency window for high power microwave applications is described. Fluid pressure, applied externally, compresses the window frame on to the edge of a dielectric disk. This pressure prevents the frame from expanding away during heating cycles irrespective of the differential thermal expansion between metal and dielectric. Silica and ceramic disks have been successfully sealed to stainless steel or copper frames and baked at 450° C.

1. Introduction

THE design of optical and radio-frequency windows for bakeable metal vacuum systems is limited by the differing thermal expansions of available materials. The borosilicate glasses are suitable for many requirements, but for high power microwave valves the window is often the limitation in the maximum power which can be produced due to the electrical loss of the glass. The use of high alumina ceramics has been a major step forward, but these also have limitations in various ways.

Silica has very good microwave dielectric properties, though its use as a radio-frequency window may be restricted by its relatively poor thermal conductivity. Due to the very low thermal expansion of silica (0.5×10^{-6} in./in. deg C) bakeable vacuum seals of any kind are difficult to make and a window type seal of 2 in. to 4 in. diameter presents a major problem. It was to overcome this problem and to find the limitations of silica as a radio-frequency window material that the window to be described was developed.

2. Description

The design of window shown in the upper part of Fig. 1 is made by copper brazing two stainless steel tubes together. The inside diameter of the complete frame is then silver plated to a thickness of 0.006 in. (Baker Silva-Brite plating process, Engelhard Industries Ltd.). The silica disk is held accurately in the middle of the frame axially and a nitrogen gas pressure applied to the channel between the two tubes. This slightly deforms the inner tube of the frame and so grips the disk. A generous radius on the edge of the disk allows the stainless steel to wrap round the window slightly and ensures that all the forces on the window are compressive.

An initial heating cycle is necessary to make a vacuum seal between the silver plating on the inside of the frame and the edge of the silica disk. When silver and silica are held in intimate contact and heated in air, a reaction takes place forming interface compounds which, although mechanically

weak, are vacuum tight. Seal strength is obtained, since during heating cycles the seal is kept in strong compression by the gas pressure despite differential expansion.

During the heating period to form the vacuum seal, which is carried out in an oxidizing atmosphere at 450° C, and also during any subsequent heating, the N₂ pressure

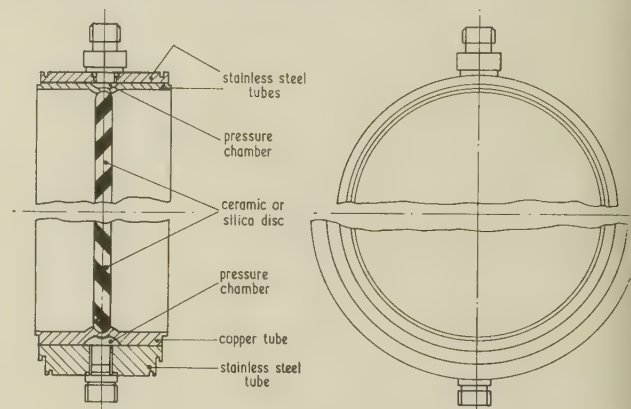


Fig. 1. Window frame design.

temperature relationship to be maintained is shown in Fig. 2. On cooling down the normal contraction of the metal frame assists in keeping the seal under strong compression. The system used to apply this pressure is shown in Fig. 3.

When the window is at room temperature, the N₂ pressure is removed and the channel can be used if required for water cooling.

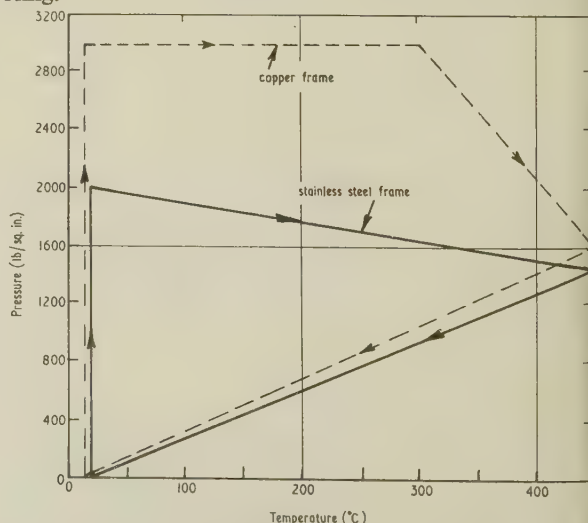


Fig. 2. Temperature-pressure relationship.

* U.K. Patent Application No. 481/59.

2.1. Ceramic windows

Ceramic windows have also been successfully sealed into the same design of window frame although the method of making the vacuum seal is different. To obtain a vacuum seal the ceramic must first be metallized on the curved surface. A diffusion weld then takes place between the silver plating on the frame and the metallized ceramic.

The temperature required to make the seal is only 450° C which enables a simple metallizing technique to be used. This is a commercially available liquid silver (Johnson Matthey Liquid Burnish Silver, grade 50 FG) which is painted on the edge of the disk and fired on in air at 750° C.

2.2. Copper frame

It was originally considered that the inner tube of the window frame would be best made from copper and a number of seals to silica and alumina ceramics were made and used. However, at 450° C the copper is annealed and with sufficient pressure applied to make the seal, the copper slowly and continuously creeps inwards around the edge of the dielectric. This restricts the total baking time to about 48 hours.

The design used is shown in the lower part of Fig. 1. The important difference from the stainless steel type being the ease in wall thickness of the inner tube. The manufacture of the frame is much the same as the stainless steel design except that silver-copper eutectic solder is used to join the tubes together. The inside of the copper tube is silver plated and seals made as described previously. The pressure-temperature relationship is shown in Fig. 2. It will be seen that the applied pressure is reduced above 300° C in the copper rapidly anneals. The high pressures required at low temperatures are not readily obtained from standard gas cylinders, so oil (Shell Voluta 45) was used as pressurizing fluid; the system is shown in Fig. 3. The

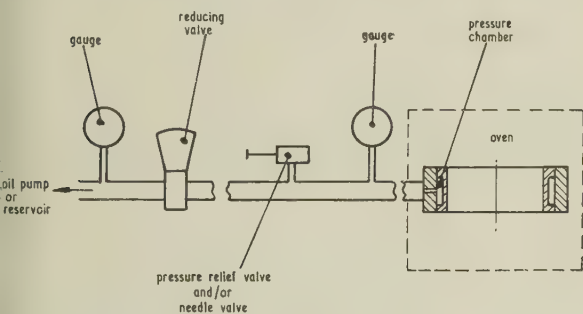


Fig. 3. Pressurizing system.

oil used was found satisfactory for baking times of up to 48 hours at 450° C, beyond this the system is likely to become blocked by the decomposition products of the oil and must be cleaned and re-filled.

The disadvantages mentioned make the use of a stainless steel frame to be preferred, but there may be applications which dictate the use of copper, for example where high thermal or thermal conductivity through the window frame is required.

3. Design

A precise design from formula can only serve as a guide. The effects of past history, work hardening, annealing and

creep strength are variable factors and are difficult to define for any particular condition. However, use of the formula given below provides an approximate prediction of the fluid pressures required.

For short thin cylinders ($l/D < \sqrt{(D/T)}$ and $l/T < 150$),

$$P_c = 1.85 FT/D$$

where P_c = collapsing pressure in lb/in², D = outside diameter = 4.1 in., T = wall thickness = 0.018 in., F = compressive yield stress.

For stainless steel,

$$F = 140\,000 \text{ lb/in}^2 \text{ at } 20^\circ \text{ C} = 91\,000 \text{ lb/in}^2 \text{ at } 450^\circ \text{ C}.$$

Hence, at 20° C,

$$P_c = 1150 \text{ lb/in}^2$$

and at 450° C

$$P_c = 740 \text{ lb/in}^2$$

The wall is not required to collapse continuously but more pressure than calculated can be applied due to the support provided by the window disk, and for stainless steel the following pressures were adopted:

$$2000 \text{ lb/in}^2 \text{ at } 20^\circ \text{ C}, 1400 \text{ lb/in}^2 \text{ at } 450^\circ \text{ C}.$$

For copper, with a wall thickness of 0.1 in. the pressures used were

$$3000 \text{ lb/in}^2 \text{ at } 20^\circ \text{ C}, 1600 \text{ lb/in}^2 \text{ at } 450^\circ \text{ C}.$$

Fig. 4 gives details of the various dimensions.

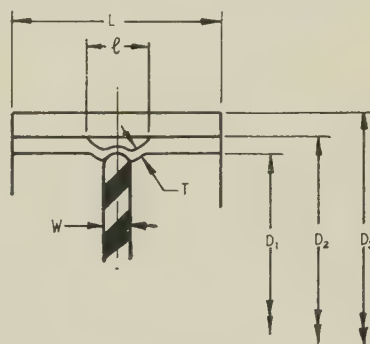


Fig. 4. Design details.

Dimensions (inches)

	Window frame material	
	Stainless steel	Copper
W silica	0.284	0.284
W ceramic	0.186	0.186
T	0.018	0.1
D_1	4.053	4.053
D_2	4.25	4.53
D_3	4.625	5.45
l	0.625	0.625
L		

For radio-frequency purposes this depends upon the dielectric properties of the window, normally not less than $1\frac{1}{2}$ in.

4. Performance

The following materials have been vacuum sealed into metal window frames and baked many times at 450° C: Silica, Spectrosil, Sintox, Coors AI200, Wesgo AL399 and Wesgo AL300.

A number of these have been fitted to sealed-off klystron amplifiers and radio-frequency transmission tests are being carried out. Windows are leak checked on an omegatron

or a mass spectrometer and some windows have been sealed off at 10^{-7} millibar for many months.

Acknowledgments

We would like to record our thanks to those whose efforts

and enthusiasm have contributed to this work. Among them are H. J. Curnow for the electrical design, C. A. Tearl for the preliminary experimental work and W. P. Barr and J. Sim on the constructional side. Acknowledgment is also made to the Admiralty for permission to publish this paper.

Low-inductance capacitor banks and linear pinched discharges

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Abstract

Details are given of low inductance capacitors, and capacitor banks with energy storages in the range 1 to 10 kJ capable of giving maximum currents of 1.2 MA and rates of rise of 6×10^{12} A/s. The working voltage in the work described is 10 kv, but the techniques have been used at higher voltages, up to 40 kv. An outline of the measurement techniques, used in the study of linear pinched discharges in low-pressure deuterium with these banks, is given.

Introduction

THE work described here was initiated to meet a need for a high brightness light source for use in the development of high-speed photometric and photographic equipment, for which purpose the discharge of a capacitor bank into a suitable load seemed most promising. The design approach has been to restrict the energy storage in the capacitor to a moderate value and to concentrate on delivering this energy to the load in the shortest possible time; in this application the duration of the pulse is not of great significance, while portability is at a premium. In view of the interest in thermonuclear processes, the work was extended to include the production of intense discharges in deuterium at low pressures.

The primary design problem is to fix the values of capacitance and working voltage most suitable for a particular load. Clearly, in order that most of the stored energy should be delivered to the load, the capacitor bank should have a resistance and inductance small compared with the load.

The differential equation governing the discharge is non-linear because of the varying inductance and resistance of the load, and a precise design study is not possible in the absence of detailed information on its behaviour, but an adequate general picture of the characteristics of a bank suitable for a particular load can be obtained from consideration of a linear circuit, in which this is replaced by one with constant resistance and inductance of appropriate values. The solution for this case is well known and has the form

$$i = \frac{E}{L}(n^2 - b^2)^{-1/2} \exp(-bt) \sin(n^2 - b^2)^{1/2}t \quad (1)$$

where $b = R/2L$ and $n = (LC)^{-1/2}$.

Straightforward manipulation of this equation gives

$$\text{maximum } di/dt = E/L \text{ at } t = 0$$

and maximum

$$i = \frac{2E}{R}(n/b)^{d-1} (1 + 1/d)^{-d} \text{ at } t = b^{-1}(\theta/\tanh \theta)$$

where $d = b(b^2 - n^2)^{-1/2}$ and $\cosh \theta = b/n$.

From the point of view of feeding energy into the load quickly, these expressions show the advantage of working at as high a voltage as practicable, at least until the bank inductance, which increases with working voltage because of the necessity of using increasing thicknesses of insulation becomes comparable with the load inductance. Eqn (3) shows that it is uneconomic to increase the capacitance far beyond the value giving critical damping, since the peak current increases by only 17% for a capacitance twice this value and by less than 36% when the capacitance becomes very large.

An additional major problem is the provision of a fast acting switch which has the required current-carrying capacitance (of the order of 10^6 A) and a sufficiently low inductance and resistance.

Capacitor design

Tests were carried out on a number of commercial available high-voltage capacitors to determine their suitability for this work. The results indicated that an inductance of 300 to 500 μH could be expected for a 1 μF , 10 kv unit, and the variation for units of different capacitances suggested that a large part of the inductance was due to the system used for making connections to the plates.

In an attempt to improve on these figures, two prototype parallel plate capacitors were constructed. The first used one hundred plates of 0.001 in. copper with 0.005 in. polystyrene insulation, which gave a 0.38 μF , 10 kv working unit with an inductance of 8 μH and 40 $\text{m}\Omega$ resistance. The second used 200 plates of 0.001 in. copper with 0.002 in. Melinex insulation (I.C.I., Ltd.), which gave a 3.3 μF unit with 25 μH inductance and 40 $\text{m}\Omega$ resistance. Although this represents a considerable improvement, the labour involved in the manufacture of a large number of such capacitors is so great that an alternative solution was sought, and several methods of making connections to the foils in

ventional capacitor-roll were investigated. The first involved the use of a number of metal tabs, Fig. 1(a), extending from the end of the roll, inserted so as to make contact with one or the other of the foils during winding, which are subsequently folded over so as to make contact after the roll is completed. The tabs are positioned so that the multiple connections to each foil are on opposite sides, and connection to these is made by two wide strips of metal laid across the end of the roll with an insulating strip between. The inductance and resistance obtained depends on the number of tabs used, and were in the range 10 to 20 μH and 20 to 35 $\text{m}\Omega$ for a 0.8 μF , 10 kv unit. The use of these tabs has the advantage that the surface gap between the tab and the opposite foil is only half the gap between the two foils and there is an increased liability for breakdown to occur at this point. Another system tried was to extend the two foils

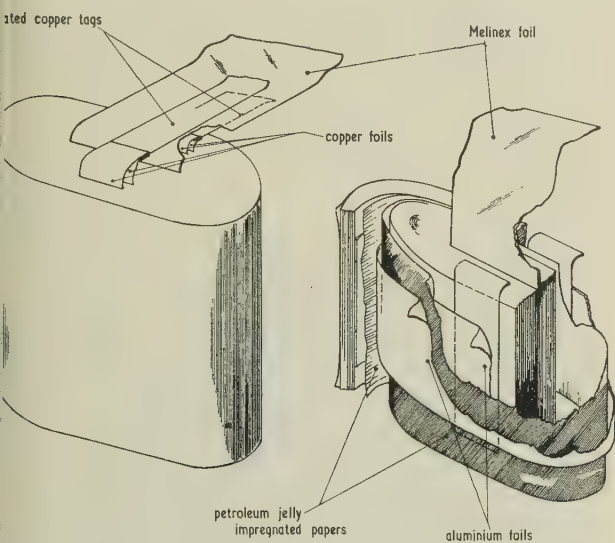


Fig. 1(a). Construction of multi-tab capacitor.

beyond the dielectric at opposite ends of the roll. This gave a 1.7 μF , 10 kv unit with an inductance of 10 $\text{m}\mu\text{H}$ and $\text{m}\Omega$ resistance, but the surface gap is again halved and difficulties were experienced in making contact to the aluminium foils at the ends.

The most satisfactory method found is the use of a pair of thin strip leads, Fig. 1(b), with three thin layers of insulation between, inserted in the roll when it is half wound so that each strip makes contact with one foil and the strips protrude from the end of the roll, separated only by the thickness of insulation used. This puts the two halves of the roll in parallel and gives the lowest inductance of those tried; $\text{m}\mu\text{H}$ for a 1 μF 10 kv unit, but the resistance is higher at $\text{m}\Omega$.

In order to attain these low inductance values, it has been found necessary, in general, to operate the capacitors with fields above the corona inception point, but the effect of corona breakdown in the dielectric is not as serious in rapid discharge capacitors as in normal service. Since the capacitors only stand-off the full voltage for a short period before each discharge, a life of only a few hours, before the damage to the dielectric is sufficient to cause failure, corresponds to a life of many thousand discharges. Discharge tests comprising several thousand discharges have been successfully carried out with all three types of rolled capacitor, even though the field in the dielectric is of the order of 100 kv/mm.

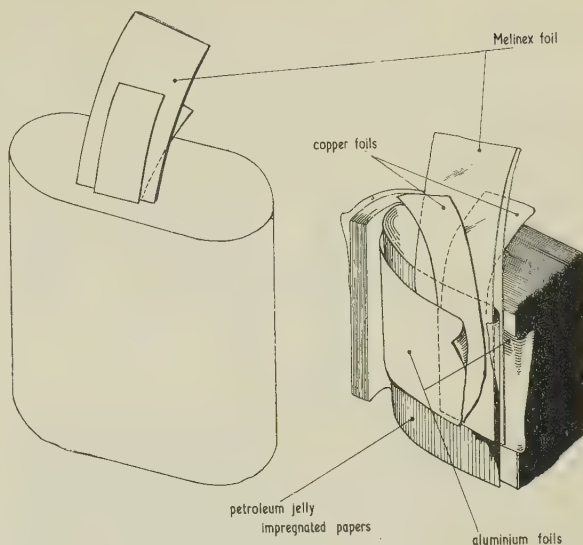


Fig. 1(b). Construction of strip lead capacitor.

Switching

A number of low-inductance switches of the triggered spark gap type have been devised, but for energies of several thousand joules these have not shown great promise; the most satisfactory form of switch found so far for experimental work is the expendable dielectric-stress switch, Fig. 1(c). The essential feature of this type of switch is a thin sheet of insulating material, sandwiched between two metal foils, which is stressed electrically by a field approaching its dielectric strength, when the application of an external mechanical stress causes a rapid breakdown of the insulator, giving a conducting path between the metal foils with very low resistance and inductance. The resistance and inductance of this type of switch can be made significantly lower than that of a triggered spark gap because the gap can be made shorter; the breakdown field in the plastic may be of the order of 10^6 v/cm, whereas, in practice, gas-filled or vacuum spark gaps seem to be limited to the range 10^4 – 10^5 v/cm, although this may not be true for very high gas pressures. The insulator and metal foils must be replaced after each operation, of course—a process which takes less than two minutes—but even here the triggered spark gap does not realize the full advantage that might be expected, because of

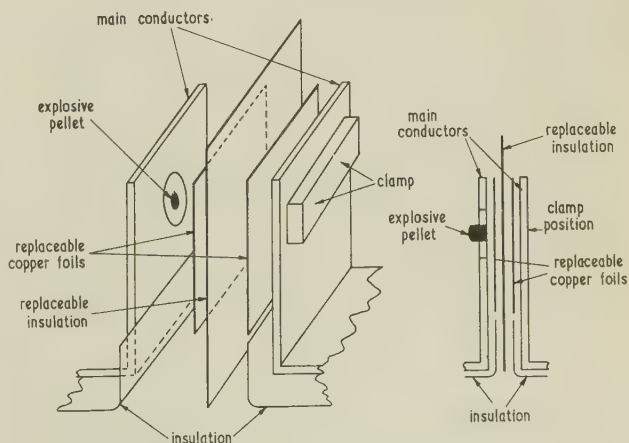


Fig. 1(c). Assembly of dielectric-stress switch.

a frequent need for readjustment or replacement of electrodes if the operating characteristics are not to vary significantly at these levels of energy dissipation. The use of a large number of triggered spark gaps in parallel to reduce the overall inductance and the effects of electrode erosion, with the attendant problem of securing adequate synchronism between them, was considered inappropriate to the requirement of working on a small laboratory scale.

The switches used for the capacitor banks described here use three separate layers of 200 gauge Melinex foil as the insulator, to reduce the danger of breakdown through 'pinholes', and the mechanical stress was provided by the shock wave from a small electrically detonated explosive pellet. Another version of the switch, using a pneumatically driven pointed tungsten rod to provide the mechanical stress, has been successfully used, but in this case the facility of close synchronization to an external event is lost. The inductance of a typical example of a 10 kv switch is calculated to be 0.5 mμH and the resistance to be of the order of 0.5 mΩ, mostly in the leads. Both the calculation and measurement of these values is complicated by the fact that they would be expected to vary (a) with time, as the insulating film breaks down, and (b) with the form of the current pulse passing through the switch, owing to skin effect in the conductors. Measurements of the waveform obtained by the discharge of a small capacitor (0.07 μF) through a switch gives the rise-time of the current pulse as 10 mμs. Values of total circuit inductance and resistance obtained with banks of capacitors described below are consistent with these calculated values.

Capacitor banks

The inductance, working voltage and energy storage of a practical capacitor roll is restricted by manufacturing techniques, particularly by the width of winding machines available, and a useful capacitor bank for these purposes is necessarily composed of a number of capacitor rolls connected in parallel, or series-parallel arrangements. Once a basic unit has been selected the required energy storage or the acceptable physical size determine the number of units to be used. Having fixed the energy storage, the next step is to fix the capacitance so as to satisfy the rather indefinite criterion of 'feeding in the energy as quickly as possible'. One approach is to maximize the peak power dissipated in the resistance of the load. Further manipulation of Eqn (1) gives the peak power as

$$(4E^2/R) \cos^2 Q \exp(-2Q/\tan Q) \quad (4)$$

where $Q = \arccos b/n$, and this has its only maximum, for Q real or imaginary, at $Q = 0$, i.e. $b = n$, the critically damped condition, which gives the optimum capacity as $4L/R^2$.

An alternative approach, which is perhaps more realistic, is to maximize the fraction Ω of the stored energy which is dissipated in the resistance of the load up to some selected time t .

Eqn (1) gives eventually

$$\begin{aligned} \Omega &= 1 - \exp(-2\tau) - 2\tau(1 + \tau) \exp(-2\tau) \\ &\times \left[\frac{\sin 2\theta}{2\theta} + \tau \left(\frac{\sin \theta}{\theta} \right)^2 \right] / (1 + \tau) \\ &= 1 - \exp(-2\tau) - 2\tau(1 + \tau) \exp(-2\tau) \cdot F \text{ say} \end{aligned} \quad (5)$$

where $\tau = bt$ and $\theta = (n^2 - b^2)^{1/2}t$.

The value of θ which minimizes F , and therefore maximizes Ω , depends on the predetermined value of τ .

When τ is small, F is a minimum for $\theta = 2.25$; for large values of τ , F is a minimum for $\theta = \pi$; for intermediate values of τ the optimum value of θ lies between these two values. The case when τ is small is not of practical interest, since Ω is also small, while with τ large the value of F is unimportant because of the overriding effect of the exponential multiplier.

In the experiments under consideration it was decided to maximize Ω for $\tau = 1$, i.e. roughly over the period of the initial current rise. In this case the optimum value of θ is 2.50, and, since one has $\theta^2/\tau^2 = (n^2 - b^2)/b^2$, this gives $b^2/n^2 = \tau^2/(\tau^2 + 6.25)$,

$$\text{i.e. the optimum capacity} = \frac{4L}{R^2} \frac{\tau^2}{\tau^2 + 6.25}.$$

Ω shows only a weak dependence on θ over a limited range in this region, and Eqn (6) can be used as it stands when τ is of the order of 1, without introducing large departures from the optimum condition.

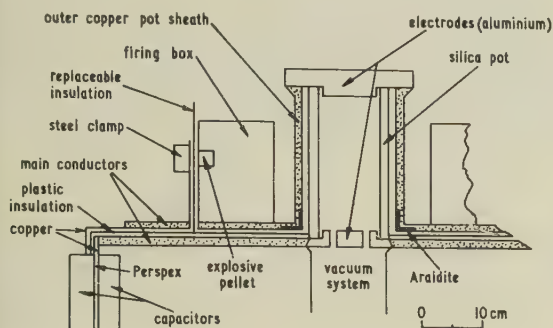
Having fixed the energy storage and capacitance of the capacitor bank, the working voltage is also fixed and it is necessary to verify that the inductance of the bank is small compared with that of the load; if it is not, it can usually be reduced by using smaller capacitance basic units. In the work described here all the capacitor banks have consisted of 10 kv basic units connected in parallel.

The first bank constructed was of $72 \times \frac{1}{2} \mu\text{F}$ commercial high-voltage capacitors with conventional terminals, stacked in vertical rows of four, with the two terminals in a horizontal plane, connected at the top end to the periphery of a pair of circular plates, 75 cm diameter with 0.03 in. polythene insulation between, by means of strip transmission lines. The explosive switch was mounted centrally underneath the plates and the load mounted above, between the switch and the top plate. This arrangement gave an inductance of approximately 6 mμH and a resistance of 10 mΩ external to the load. The peak current obtained with this bank discharging into a thin wire, was about 500 kA.

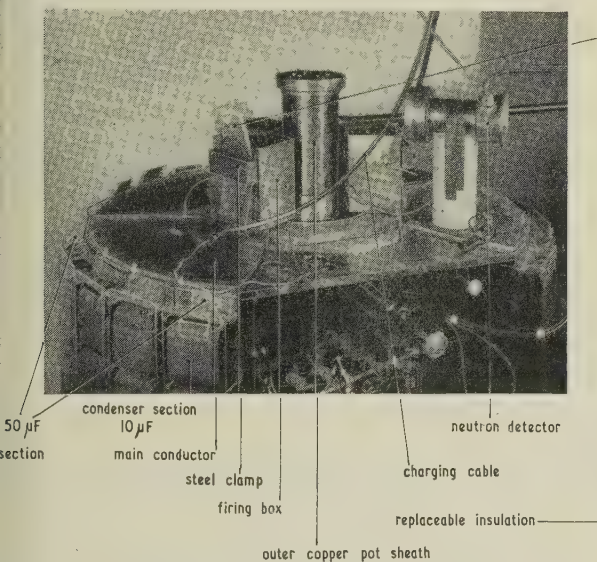
The second bank, which was used for the bulk of the work reported here on discharges in low-pressure gases, consisted of four sub-units of fifty 1 μF capacitor rolls (Fig. 2). The two main conducting disks, 90 cm in diameter, were separated by 0.018 in. of Melinex insulation and the upper disk was divided into four sectors, each sector being switched separately to the central discharge chamber. The capacitor rolls were of the strip-lead type and ten rolls, in two rows of five, were clamped back to back with the leads folded back to make contact with a strip transmission line, consisting of a pair of thin copper strips separated by 0.006 in. of Melinex insulation clamped between the two rows. This gave a 10 μF, 10 kv unit with an inductance of about 1.5 mμH. Five of these units are connected to each sector of the top conductor plate. Each switch consists of two replaceable copper foils separated by 0.006 in. of Melinex foil, clamped together; when the four sections are used together the closing of the four switches is simultaneous to within 100 mμs. The discharge tube is of silica 30 cm long, 10 cm internal diameter with 1 cm wall. The current return path is a copper tube fitting closely round the outside, and the inductance associated with a discharge close to the walls is about 13.5 mμH; with a cylindrical pinched discharge 2 cm in diameter, say, it rises to 97 mμH.

The form of the current oscillation is determined by direct measurement of the voltage developed across a thin copper

platinum foil of 0.1 to 0.3 m Ω resistance connected so to have a low self-inductance. With the discharge tube short-circuited, a single section (50 μ F) gives a peak current of 850 kA and the period and damping factor of the oscillation give an average inductance of 3 m μ H and an average resistance of 5 m Ω ; the value of the peak current combined with the derived inductance value gives a resistance of 4.8 m Ω , of which are in reasonable agreement with the calculated values of 2.4 m μ H and 3.7 m Ω . With the discharge tube



(a) Capacitor bank discharge circuit.



(b) Capacitor bank mechanical assembly.

Fig. 2

operation, filled with deuterium at 200 μ pressure, the measured peak current for one 50 μ F section is 250 kA; the average inductance and resistance calculated from the ringing frequency and damping factor are 26 m μ H and 20 m Ω . The resistance calculated from the peak current and inductance is 20.9 m Ω . The rate of change of current is also measured directly by means of a Rogowski coil placed between the discharge tube and the return path. Both monitors indicate that three or four pinches occur during the rise to peak current, when the chamber is filled with deuterium or hydrogen at pressures in the range 50 to 200 μ (Fig. 3). The vacuum system is operated continuously between firings, maintaining a pressure of 2×10^{-6} mm.

Although the switches can be closed within 100 m μ s of a predetermined time, there is an appreciable delay in

breakdown through the discharge tube, occasionally as long as 50 μ s, but more usually about 10 μ s, and monitoring equipment is usually synchronized by the output from a photomultiplier detecting the light from the discharge.

A third bank of 95 μ F consisting of eight of the 10 μ F strips and three similar 5 μ F half-sections connected in parallel round the periphery of a pair of conducting disks of 25 cm radius has recently been constructed. In this case the whole bank is discharged through a single explosive switch mounted centrally above the discharge chamber. With the discharge tube short-circuited, the peak current is 1.4×10^6 A, the average resistance and inductance calculated from the period and damping factor are 3.5 m Ω and 1.8 m μ H and the initial value of di/dt is 4×10^{12} A/s. In this case, however, the inductance is reduced by a calculated 0.6 m μ H

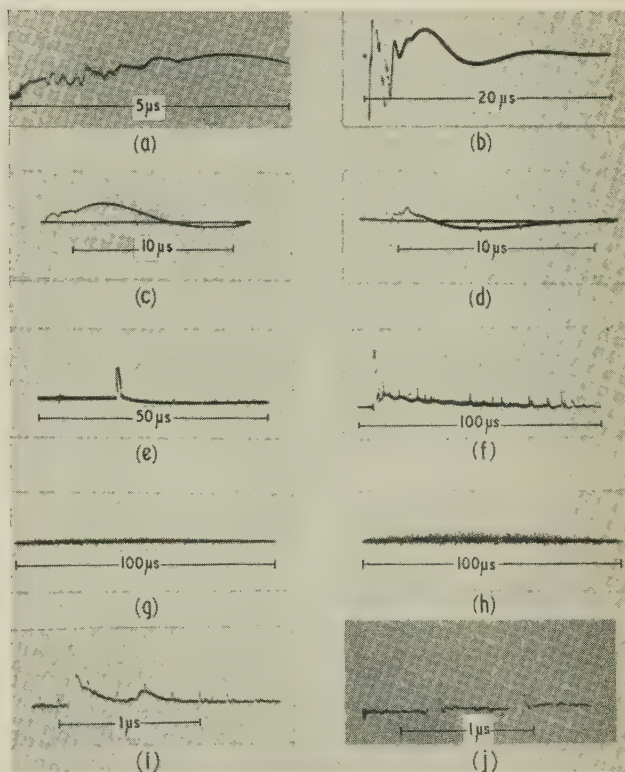


Fig. 3

- (a) Current waveform, 50 μ F section, deuterium discharge, 200 μ pressure.
- (b) di/dt waveform, 50 μ F section, deuterium discharge, 200 μ pressure.
- (c) Current waveform, 95 μ F bank, deuterium discharge, 180 μ pressure.
- (d) di/dt waveform, 95 μ F bank, deuterium discharge, 180 μ pressure.
- (e) Scintillation counter output, logarithmic amplifier.
- (f) Scintillation counter output, linear amplifier.
- (g) Scintillation counter output, 130 μ s after pulse, without cadmium sheath.
- (h) Scintillation counter output, 130 μ s after pulse, with cadmium sheath.
- (i) Scintillation counter output, 27 cm from discharge tube.
- (j) Scintillation counter output, 2.5 m from discharge tube.

owing to the changes necessitated by removing the discharge chamber. With the chamber in operation filled with deuterium to a pressure of 170 μ , the peak current is 255 kA and the initial value of di/dt is 3×10^{11} A/s. The resistance

and the inductance calculated from the period and damping factor are 19 mΩ and 50 mμH; the initial inductance is approximately 30 mμH.

It is of interest to compare the performance of these banks with others which have been described. The third bank described here, Totem, which has an energy storage of only 4.75 kJ, is capable of delivering a mean power of 650 MW for 5 μs to a 50 mμH, 15 mΩ load. By reducing the inductance of the load to 12 mμH it should be possible to increase the mean power to 1.2 kW for 1.5 μs. The volume occupied by this bank is about 1 m³, and this is much smaller in proportion to its energy storage than for banks using conventional capacitors and switches. The table gives comparative figures for several banks that have been described elsewhere. The quantity η , which is given in this table, is

switch, and the flexibility given by a planned replacement of capacitor banks is an advantage rather than a disadvantage.

Experimental results

The banks described have been used to explode thin wire in air and under water and to produce sparks in high pressure (100–200 atm) and low pressure (50/250 μ) hydrogen and deuterium.

Both the exploded wires and the high-pressure gas discharges gave surface temperatures of the order of 30 000° and, from the original point of view, proved satisfactory. However, in view of the general interest in thermonuclear processes, the work was extended to low-pressure gases in an attempt to obtain much higher temperatures.

	Energy storage (kJ)	Working voltage (kV)	Bank inductance (mμH)	Estimated bank resistance (mΩ)	Mean power (GW)	Load A Time (μs)	η	Mean power (GW)	Load B Time (μs)	η	Switch type
U.C.R.L. ⁽¹⁾	15.6	50	200	110	0.32	2	0.04	0.25	1.5	0.02	Single spark gap
Livermore											—
C.E.A. ⁽²⁾	37	35	60	25	1.7	3	0.14	1.4	1.5	0.06	—
Fontenay											
Columbus II ⁽³⁾	25	50	35	—*	3.6†	2	0.29†	5.7†	1.5	0.34†	Single spark gap
Los Angeles											
Institute of Phys. ⁽⁴⁾	75	50	20	20	5.4	2.5	0.18	10.3	1.5	0.21	Single spark gap
Uppsala											
Oswald ⁽⁵⁾	6	10	8.5	4.5	0.53	3	0.26	1.0	1.5	0.26	Multiple spark gap
A.W.R.E. Aldermaston											
Maggi ⁽⁵⁾	45	30	5.5	—*	5.5†	3	0.37†	10.3†	1.5	0.36†	Multiple spark gap
A.W.R.E. Aldermaston											
Totem	4.75	10	2.4	3.5	0.57	3	0.36	1.2	1.5	0.38	Single dielectric stress
A.W.R.E. Aldermaston											

* Insufficient information to allow estimate of bank resistance.

† These are maximum figures assuming zero bank resistance; for 10 mΩ bank resistance these figures become:

Columbus II 2.6 GW, 0.21; 4.6 GW, 0.28
Maggi 2.4 GW, 0.27; 7.2 GW, 0.24

Load A is 50 mμH, 15 mΩ and load B is 12 mμH, 15 mΩ.

(1) Anderson *et al.* 1958; (2) Aymar *et al.* 1958; (3) Hagermann and Mather 1958; (4) Siegbahn and Ohlin 1958; (5) Curran *et al.* 1958

the ratio of the energy dissipated in the load in the stated time, which is roughly the rise time of the current pulse with the stated load, to the initial stored energy.

The main advantage of this type of bank is that it makes possible experimental studies of high-temperature plasmas with only modest equipment and on a normal laboratory scale; a projected design for a 30 kJ, 40 kV bank, for example, occupies only 2 m³. A secondary advantage, due to the low inductance, is the reduction of the radiated electromagnetic field, which is such as to allow the operation of high-speed oscilloscopes within ten feet of the bank without special screening. The switch has the advantage also that there is little radiated interference from the 'trigger' lead since the firing circuit can be isolated electrically from the bank. The banks are restricted to repetition rates less than once every two minutes by the switch, and to a total life of five to ten thousand discharges by the capacitors at present, but in the authors' experience the time taken to process and analyse the data obtained limits the repetition rate far more than the

Using one 50 μF section with the discharge chamber filled with deuterium at pressures ranging from 50 to 250 μ, penetrating radiation was observed, with a scintillation counter placed 25 cm away, after a few firings. As the number of firings increased, radiation was observed more frequently with pulses appearing in more than 90% of the discharge after one hundred discharges had been passed. The counter used initially was a 3 litre solution of paraterphenyl in toluene; subsequently several other counters using disks of plastic scintillator were used.

The radiation which is detected has passed through 1 cm of silica, 3 mm of copper and about 10 cm of air before being detected, which effectively eliminates the possibility that it consists of charged particles. If it were x-radiation the photon energy must be in excess of 50 keV; it is still observed with a $\frac{3}{8}$ in. lead screen in front of the counter, which would imply energies of the order of 400 keV for the photons. The presence of a neutron component was established first by surrounding the scintillator with a cadmium sheath, which

rise to delayed γ -pulses due to capture of neutrons in the scintillator, and secondly by detecting and measuring a time of flight associated with the radiation. Figure 3(i) shows the output from the unmodified counter with some after-pulsing observable up to 250 μ s, while 3(h) shows the output from the sheathed counter, with a very marked increase in the after-pulsing due to the disintegrations.

For time-of-flight measurements two scintillation counters are set up in a plane perpendicular to the axis of the discharge tube, one close to the discharge tube and the other at a distance varying between 1 and 3 m with a 3 cm lead screen in front of it. Fig. 4 shows the observed time of arrival of the front edge of the pulse plotted against distance, which indicates a velocity of 2.5×10^9 cm/s corresponding to 3.4 MeV neutrons. The time resolution required for this measurement is high, and the accuracy correspondingly low,

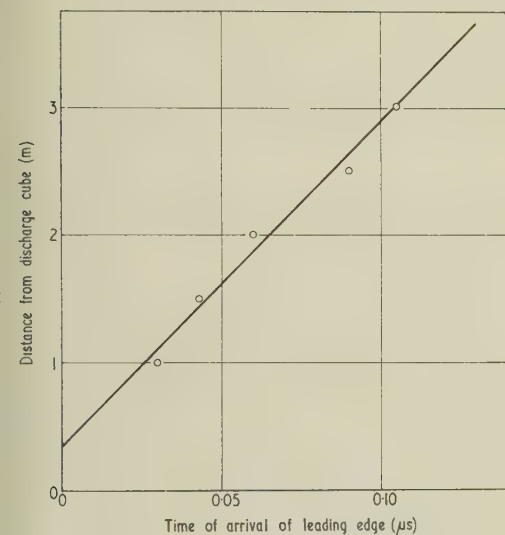


Fig. 4. Time of flight of radiation.

the difference between the measured 3.4 MeV and the expected 2.48 MeV for D-D neutrons seems statistically significant. Without the lead shield the leading edges of the pulses from the two counters are simultaneous within the resolution of the equipment, suggesting that some x-rays are also present. However, no pulses of radiation were observed in a series of six consecutive firings with hydrogen replacing the deuterium, while they were observed immediately on refilling with deuterium, which suggests that the effect is due to x-rays produced by scattered neutrons or fusion reactions.

Measurements were made of neutron yield using the liquid scintillator with an E.M.I. type 6260 photomultiplier and a logarithmic amplifier. The electronic system was calibrated over a 70 dB range using 30 m μ s light pulses from a rotating mirror device, and the sensitivity of the scintillator was determined using 1 MeV γ -rays from a ^{60}Co source, it being assumed that the effect on the phosphor was similar to that of the neutrons within the accuracy of the experiment. If isotropic emission is assumed the detector covers a range of 10^2 to 5×10^5 particles. Neutron yields obtained were in the range of 1×10^3 to 4×10^5 , about two-thirds of these being greater than 1×10^4 . These values are based on the assumption that the counter acts as an integrating device, and that the pulse is short compared with the time constant.

The records indicate that the pulse is not long compared with this time, but, if it is comparable, the yields corresponding to the observed deflections will be greater by a factor depending on the ratio of the pulse duration to the time constant.

The variation of the diameter of the discharge with time has been investigated using a 'streak' camera technique. The photographs show only two pinches clearly, although three dips are observable in the corresponding current waveforms. At 100 μ pressure, for example, the first pinch takes place at 1.0 μ s after breakdown and radial velocities of 62 mm/ μ s are obtained, while the second takes place at 1.7 μ s with radial velocities up to 95 mm/ μ s. The minimum diameter during the first pinch is 13 mm (compression ratio 59) and 9 mm (compression ratio 123) during the second.

The variation of spectral distribution, in the visible and quartz ultra-violet regions, with time has also been studied. A large number of lines are found but most have been identified as ionized silicon lines, occurring after the pinches; the only deuterium line recorded is the Balmer line at 486 m μ , and this is very broad and weak. There is a marked increase in intensity of the background continuum during the pinches and also at the current maximum. The introduction of 5% of oxygen into the deuterium increases the intensity of the continuum markedly, but the oxygen may have some modifying effect on the discharge because of its higher Z-number, of course. The highest ionized level identified is OVI, from the 3^2S - 3^2P doublet, which is the brightest line during the pinches. Examples of the streak and time-resolved spectrum records are shown in Fig. 5. The lines parallel to the time axis on the streak record are due to the wire mesh used as a current return path around the discharge tube. A more detailed description of the spectroscopic work is given elsewhere (Gabriel 1959).

Discussion of results

The general features of the results obtained with discharges in low-pressure deuterium are similar to those reported by other workers, although there are differences in detail.

The duration of the neutron pulses, 0.2 μ s, is shorter than those reported by Siegbahn and Ohlin (1958), and Curran *et al.* (1958), 0.5 μ s, and by Mather and Williams (1958) 0.5 to 0.8 μ s.

The excess neutron energy given by the time-of-flight experiments is measured in a plane perpendicular to the electric field, and is therefore not consistent with a Colgate type $m = 0$ instability (Anderson *et al.* 1958), but could be consistent with the mechanism proposed by Tuck (see Anderson *et al.* 1958) if the magnetic field in the region of the 'neck' were insufficiently large to deflect the deuterons, although this result must be regarded with caution since the statistical significance of the excess is border-line.

The pinch velocities given by the 'streak' records are of the same order as those given by Artsimovitch *et al.* (1957) (a few centimetres per microsecond), Lukyanov and Sinitsin (1957) (6 to 8 cm/ μ s), and Bodin *et al.* (1959) (7.5 cm/ μ s). Comparison of the time-resolved spectra with those of Lukyanov and Sinitsin (1957), and those for Zeta (Butt *et al.* 1958) show that the excitation temperature is higher in the present case. The highest transitions in the quartz ultra-violet region in the Lukyanov-Sinitsin results are Nv 6-7 transitions, with excitation energies about 90 eV above the ground state of the corresponding ion, and O v 3^3S - 3^3P for Zeta, with excitation energies about 70 eV, compared with the O vi 7-8 transitions with excitation energies 130 eV above the corresponding ion

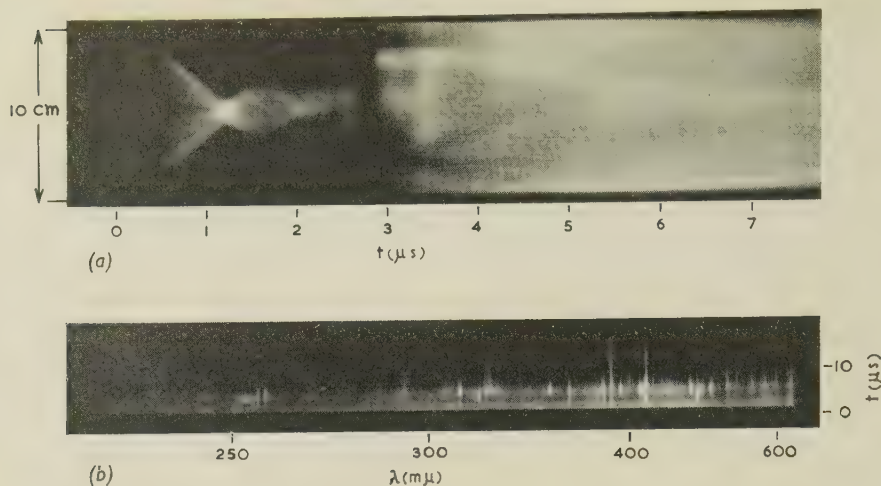


Fig. 5

- (a) Streak photograph, deuterium discharge, 250 μ pressure.
 (b) Time resolved spectrogram, deuterium + 5% oxygen, 200 μ pressure.

ground-state, which give strong lines during the pinches. This conclusion is confirmed by the fact that the Balmer lines are suppressed until a late stage of the discharge, none appearing until several microseconds after the pinches.

The time-resolved spectra and the streak records show that there are no significant impurities in the discharge during the early stages and that the major source of impurities is the wall material, which makes its appearance, in large quantities, at about the current maximum; rather surprisingly there is no evidence of any appreciable quantities of electrode material appearing in the discharge. With a pure deuterium discharge there is no wall evaporation during the pinches, as reported by Bodin *et al.* (1959), but there is a little when the 5% oxygen-deuterium mixture is used.

All of the results discussed here have been obtained using an energy storage of only 2.5 kJ, and it is clear that the primary objective, that of developing apparatus and techniques, which will allow experimental studies of high-temperature plasmas on a laboratory scale and without incurring heavy costs, has been achieved. Subsequent work has been directed towards confirming the experimental validity of the measurement techniques, and attempts are being made to improve the time resolution of the neutron time-of-flight measurements and to extend the time-resolved spectrographic techniques to the vacuum ultra-violet region.

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Calorimeter for the continuous study of the heat production of microbial systems

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Abstract

The calorimeter described is suitable for the continuous study of the heat production of microbial systems. The instrument is self-balancing, heat production in a reaction vessel being simulated by electrical heating of an identical reference vessel. A continuous record of the electrical power supplied to the system is presented on a strip chart. Provision is made for stirring, sampling and maintenance of a controlled atmosphere. The vessels may be sterilized and are inert towards the systems to be studied.

Introduction

VERY few measurements have previously been made of the enthalpy changes occurring during fermentations carried out by micro-organisms, and no apparatus for the continuous study of these processes has been described. A calorimeter for this purpose requires several specialized features. The reaction vessel and the subsidiary apparatus incorporated in it must comprise materials capable of withstanding repeated sterilization and which are quite inert in respect to the cultures and media to be studied. A continuous recording device is desirable as the reactions may extend over several hours. To allow precise kinetic measurements, thermal lags in the system should be reduced to a minimum, and stability over the period of a reaction is essential. Provision must be made for sampling and for maintenance of a controlled atmosphere in the reaction vessel.

Description

A calorimeter satisfying these conditions has been constructed. It consists of two enclosed vessels each of 200 ml. capacity made as nearly as possible identical to one another. These vessels are contained in separate isothermal jackets, which are supported by a brass framework in a water bath controlled to ± 0.003 deg at 37°C . The vessels are maintained automatically at the same temperature so that the heat losses are essentially the same from both (Sturtevant 1945). After unsuccessful trials with stainless steel and glass, aluminium cap aluminium canisters coated internally with 'Teflon' proved satisfactory and are now being used. Thermistors (Standard Telephones and Cables, type 5250/300) are used to detect temperature imbalance between the two vessels, one being cemented externally to the bottom of each vessel with silicone electrical insulating varnish. When being assembled for experiment the bodies of the canisters are screwed into their caps which are hung from the lids of the external isothermal jackets by the tubes through which aeration and sampling are effected. A gas-tight seal is maintained by neoprene washers between the

caps and bodies of the canisters. The heaters mounted through the caps of the vessels are of small heat capacity; they are wound from 3 mil nichrome wire on to formers of 26 s.w.g. enamelled copper wire to provide a resistance of $15\ \Omega$, insulated with silicone varnish and encased in 0.5 mm

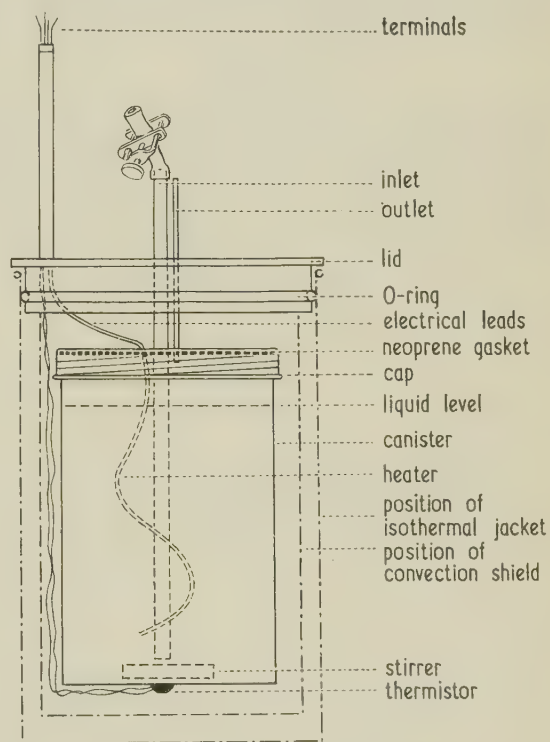


Fig. 1. The reaction vessel assembled for sterilization. The convection shield and body of the jacket are put into place after sterilization.

i.d. thin-walled silicone rubber tubing. Each heater is wound into a spiral to ensure even distribution of heat through the liquid contents of the vessels. Stirring is effected by small Teflon-encased stirring bars within the vessels driven by revolving magnets placed under the bottoms of the outer jackets, the driving motor being connected to the magnets by a flexible shaft and gear train. Electrical leads to the vessels are brought through the lids of the jackets in silicone rubber tubing, and terminate above the water level in the bath. Soldered connections are made between these terminals and the external circuits. The nylon sampling tubes from the vessels are also brought through seals in the

lids of the jackets, external connections being made with silicone rubber tubing. The lids are a push-fit in the jackets: water-tight seals here are made with O-rings. The vessels together with the lids of the jackets can be removed with ease from the bodies of the jackets and sterilized as assembled units. The jackets are isolated from the inner vessels by thin aluminium convection shields mounted concentrically with the jackets and the vessels, which are constrained to a fixed position by nylon threads so that a 1 cm air gap is maintained between the vessels and the convection shields.

Although this arrangement was found to reduce to a low rate heat leakage from the calorimeter, there is a corresponding disadvantage: with these in position, several hours are required to establish thermal equilibrium between the reagents and the bath. When the experimental conditions will not permit this delay, the solutions are rapidly brought to equilibrium in uninsulated vessels connected to the sample inlets of the reaction vessels: the reagents are then passed into the reaction vessels by a small pressure of gas. This procedure takes only a few minutes, so that actively fermenting microbial populations may be introduced into the calorimeter without material change in their characteristics.

Operation

The instrument operates on a principle of continuous balancing and recording which is similar to that of Buzzell and Sturtevant (1951). The thermistors attached one to each vessel are connected as two arms of a Wheatstone bridge (Fig. 2). A galvanometer in the bridge circuit drives an

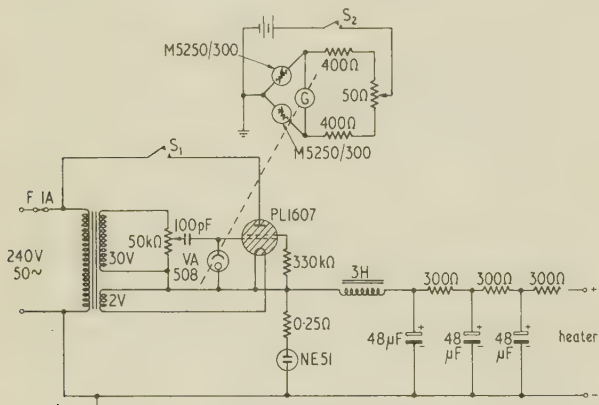


Fig. 2. The temperature-sensitive bridge and calorimeter heater control unit.

optical lever-photocell amplifier which controls a thyratron supplying current to the electrical heater immersed in the liquid within the balance vessel. The light spot shining on the photocell is made much larger than the photosensitive area of the cathode, so that the system does not lose control at large galvanometer deflections, and maximum heating rate is attained with a deflection corresponding only to a small fraction of the width of the light spot. The brilliance of the pilot lamp (type NE51) gives a visual indication of the current supplied to the heater.

The current supplied to the balancing heater is filtered to remove a.c. ripple as the measuring circuits are designed for direct current. The voltage developed by passing the current through a metering resistor is applied to the grids g_3 and g_5 of V_1 (Fig. 3) through a dividing network. This arrangement produces a voltage output at the anode of V_1 proportional to the square of the input voltage. (The electrical quantity

required for the measurement of power dissipated in a heater of fixed resistance is the time integral of the square of the voltage applied.) Adjustment of the potential applied to g_1 gives a linearity control, and operating g_1 at fixed potential cancels the effect of heater-voltage variation (Grey 1948, p. 465).

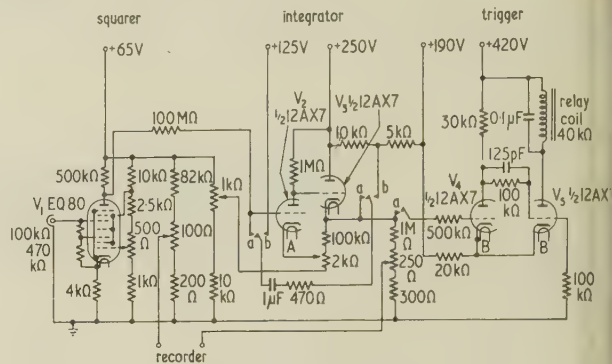


Fig. 3. The metering circuits.

The output from the squarer is fed into an electronic integrator of the 'amplified time-constant' type (Grey 1944, p. 475) and the output voltage developed at the cathode of V_3 is continuously recorded on a strip chart. The cathode loads of V_2 and V_3 are connected to a potentiometer giving a zero adjustment to allow for component variations.

The integrator employs positive feedback to produce infinite gain. The feedback adjustment is conveniently set by reference to the record presented on the strip chart recorder. The correct setting gives a linear trace with a constant voltage input. The voltage at the cathode of V_3 rises throughout the cycle of integration until it reaches the level at which the Schmitt trigger circuit V_4 and V_5 fires. This energizes a relay which connects the integrating capacitor across two points at fixed voltage, which partially discharges the capacitor. The relay holds on for about 50 ms before the capacitor is reconnected to the integrator. Thus the capacitor is cycled between fixed voltage limits. As the relay contacts form part of the high-impedance input circuit of the integrator, Teflon insulation is used between them.

Stability of the electrical components is of considerable importance as the reactions under observation may run for several hours. A stabilized power supply is incorporated with a series valve regulator and a compound neon stabilizer (Ferranti, type STV 280/80) giving the voltage levels required for the various stages of the measuring circuits, which are necessarily directly coupled. The thermistor bridge and the light source are driven from accumulators of very large capacity and the lamp is run at less than its rated voltage to ensure long life.

Performance

Over several weeks of intermittent operation, the variation in the output recorded on the strip chart was $\pm 3\%$ for constant input voltage to the metering circuits, the response at various voltage input levels following a square law. Each count on the strip chart corresponds to about 1 cal and the calibration is determined after each experiment by passing a known quantity of electricity through the heater of the reaction pot at a rate comparable with that observed in the experiment and allowing the calorimeter to balance the consequent heat evolution automatically. The amount

t required to produce the error signal driving the balance is 0.5 cal at the maximum heating rate of 1 cal/min, the thermal lag when following a steady rate of production of heat is about five minutes. The fastest reaction ever studied has been completed in 40 minutes so that this is not troublesome. The sensitivity is 0.4 cal/h, corresponding to 0.001 deg rise in a 200 ml. sample. To be certain that very small rates of heat evolution are detected,

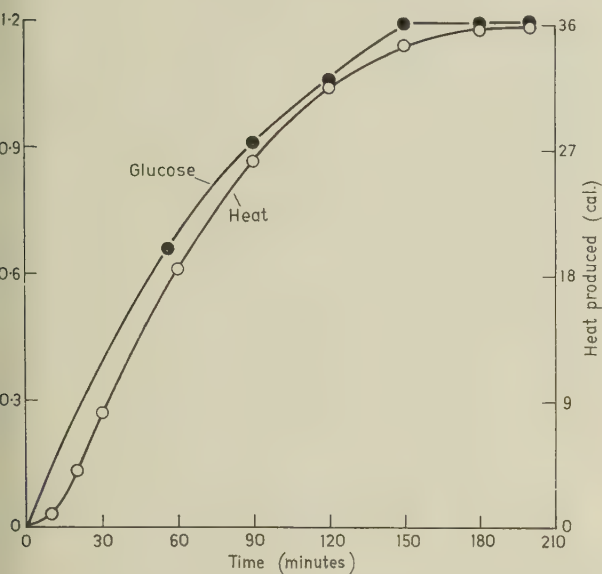


Fig. 4. The heat production accompanying the fermentation of glucose to lactic acid by a washed cell suspension of *Streptococcus faecalis*.

the temperature-sensitive bridge is not balanced exactly before a reaction, but set so that the reaction vessel is apparently very slightly hotter than the balance vessel, even though the two are in exact thermal equilibrium. This has the effect that the automatic controls endeavour to correct for the imbalance and a small input of heat is supplied to the balance vessel. Soon the heat losses from the vessel balance this input and a steady small rate of heating or 'drift' is set up. Very small rates of reaction now become apparent as a change in the rate of drift. This procedure is due to J. M. Sturtevant (private communication).

The thermistors are apparently unaffected by the heating they receive during sterilization. Both are treated identically, and it has been found that the ratio of their resistances has changed by less than 0.5% after repeated autoclaving at 120°C. The performance of the instrument in studying a bacterial fermentation is illustrated in Fig. 4.

Acknowledgments

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recording flowmeter using a radioactive float

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Abstract

Instrument of the type comprising a float in a vertical tapered tube is often suitable for measuring low rates of flow but difficulties arise in obtaining remote indication, recording or control owing to the small physical size of the float and the consequent failure of conventional methods of detecting its position. This paper describes a method in which a radioactivated float and low-voltage, high-current Geiger tubes have been used to overcome these difficulties.

Introduction

THE measurement of rates of gas flow in a chemical process such as the hydrocarbon synthesis plant of the Fischer-Tropsch process, presents a major problem in the determination of the most suitable type of instrumentation to be employed. A programme of research work on this process, which has been carried out in bench and

pilot-scale plants, both at Warren Spring Laboratory and at the former Fuel Research Station, has presented such problems.

One of the more difficult of these has been the measurement and recording of low rates of flow of gaseous mixtures at pressures of 20 atmospheres or above. Typical values of these rates of flow are 0.25 to 1.5 cu ft/h, measured at N.T.P. The need to work at elevated pressures made it difficult, or even impossible, to employ many of the conventional types of flowmeter. Other limitations were imposed by the nature of the process itself. For example, a large drop in pressure at, or across, the measuring meter, could not be tolerated owing to the tendency for valuable products of the reaction to condense, causing blocking in the system and other undesirable effects.

Before describing the instrument developed to surmount these difficulties, a brief review of conventional methods used in flow recording instruments, and their limitations, is given.

Limitations of conventional meters for low flow rates

Conventional methods of measuring low rates of flow employ meters which can be classified under three broad groups:

- (1) Displacement meters, fitted with timing devices.
- (2) Differential pressure meters.
- (3) Variable aperture meters.

The first of these groups includes wet gas meters, both the nutating bell and the rotating drum types. Both of these use a liquid seal, and can readily be obtained in a size suitable for measuring rates of flow as low as 0.25 cu ft/h, i.e. 0.1 litre/min N.T.P. They are normally indicating meters only, some being fitted with mechanical revolution counters, but could, with suitable modifications, be adapted to give permanent records of flow. Use of this type of meter at elevated pressures would entail a pressurized chamber of large dimensions, which was considered to be impracticable for the Fischer-Tropsch process.

Differential pressure meters with fixed aperture, such as the Venturi tube, capillary tube or orifice plate meters are widely used, since they are able to measure the flow of most industrial fluids, with very few exceptions. This type of meter consists of a primary element inserted into the pipeline, generating a differential pressure, the magnitude of which is a function of the rate of flow. A secondary element is needed to measure the differential pressure, and translate it into terms of flow. A complication arises owing to the necessity of measuring the small differential pressures at a level of 20 atmospheres.

Variable aperture differential pressure flowmeters operate in such a manner that the effective size of the measuring orifice or flow passage varies with the flow rate. The magnitude of the displacement of a moving element from its zero position is a measure of the rate of flow, and with a suitable size of moving element, can be employed to measure very small flow rates. The most widely used of the variable aperture meters is the tapered tube and float type, such as the 'Rotameter'.* This meter consists of a tapered tube forming an upward flow passage with its smallest diameter at the bottom. The tapered tube contains a float having an outside diameter which just clears the base of the tube in the lowest position, where the float rests on a stop. As the flow increases, the float rises within the tube to such a position that the pressure loss across the annular orifice just balances the weight of the float. The float, therefore, attains a position of equilibrium, and the distance from the stop to the float is a measure of the rate of flow. A further advantage of the variable aperture over the fixed aperture meter for the process described in the introduction is in its ability to overcome the effects upon its accuracy of the condensation of reaction products which frequently occurs. Whereas the gas stream may hold a small droplet against a fixed aperture and alter its effective size, the float would move upwards under these conditions and be self-clearing.

For these reasons it was considered unwise to attempt the use of the fixed aperture type of meter.

Modification of the instrument for remote indicating and recording

Conventional methods of remote indication or recording from a flowmeter, such as inductive or magnetic methods,

* The Rotameter Manufacturing Co., Ltd., G. A. Platon, Ltd., etc.

are widely known. However, with low rates of flow, such methods become impracticable, owing to the small size of the float.

An optical method, consisting of a series of germanium photocells held vertically along the length of the tube, and allowing the float to interrupt a beam of light to the cells in succession, as it varied its position due to fluctuations in the rate of flow, was first tried. This was unsuccessful because the gas being metered tended to carry with it foreign matter, such as oil droplets. These, although not detrimental to the plant process, deposited a film on the bore of the meter tube, which in a period of a few days, tended to obscure the light path to the photocells, and render the instrument completely insensitive.

The present method of using a radioactive float was devised to overcome these difficulties. It employs a number of low voltage high-current Geiger tubes mounted in a metal block surrounding a portion of the length of the flowmeter tube.

Choice of isotope

Choice of isotope is governed by the following considerations:

- (1) The radiation must be hard enough to penetrate the 3 mm glass wall of the flowmeter tube without too much loss of energy.
- (2) The radiation must be of such energy that a large proportion of it will be absorbed in the 1 cm of metal between the rotameter tube and the Geiger tubes.
- (3) The isotope must have a reasonably long half-life (greater than one year).

An isotope with a low-energy gamma ray is the obvious choice, and the following were considered.

	Half-life	β -ray energies (MeV)	γ -ray energies (MeV)
Europium 155	1.7 year	0.15, 0.25	0.06, 0.1
Thulium 170	127 days	0.87, 0.97	0.084
Cerium 144	285 days	0.18, 0.31	0.134
Praesodymium 144		3.12	0.7, 2.2
Samarium 145	410 days	—	0.061
Gadolinium 153	236 days	—	0.1

The high energy gamma emission from the associated praesodymium 144 makes cerium 144 unsuitable, and the samarium and gadolinium isotopes are not yet easily obtainable. The best isotope to use would be europium 155, but this is normally prepared by an (n, γ) reaction with a cross section of only 1.24 barns, and it would take six months to obtain 0.5 mc in 20 mg of target material. Hence thulium 170 was selected for use in the prototype now described. The disadvantages of this isotope are its comparatively short half-life and the high energy bremsstrahlung arising from the 0.97 MeV β -radiation.

Choice of detector tube

In order to keep the amount of activity required to a minimum a detector was chosen which gives a high output for a small radiation flux. Halogen quenched tubes of suitable size are readily available on the market.

Typical performance for these halogen tubes is 25 μ A per r/h at an operation voltage of 525 v.

Modification of float

The float provided with the flowmeter was made from stainless steel and because of its small volume it could not

be adapted to hold the radioisotope, which for safety is to be carefully sealed in position. For the design of a new float, it may be shown from the operation of a tapered-tube flowmeter that there are two dimensions which are of first importance if the linearity and linearity of the scale are to remain unchanged. These are the mass of the float including the isotope, and the diameter of the flange at the top of the float, both of which should be the same as for the original. For these reasons, the extra volume required to accommodate the isotope was obtained by extending the length of the body of the float, making it from a less dense material (aluminium) in order that the overall mass could be kept as nearly as possible unchanged. The volume of the new float is necessarily greater than that of the original and the effect of buoyancy will be increased. Even for an instrument calibrated for use at 10 atmospheres this buoyancy has only a second-order effect owing to the fact that gaseous mixtures of low density are being metered, but if the flowmeter were to be used for liquids, then it would have to be recalibrated. Advantage must then be taken of the fact that when the density of the liquid is twice that of the liquid being metered, the calibration in units of weight is independent of fluid density over a wide range. Details of the float are shown in Fig. 1.

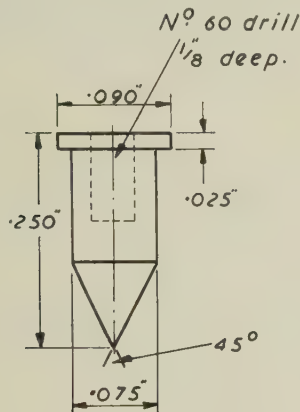


Fig. 1. Float details.

The sealing in of the isotope and the final adjustment of the float was carried out, using radio laboratory techniques, at the Radio Chemical Laboratory, Amersham.

Float filling	0.01 g Tm_2O_3
Irradiation	14 days at a pile factor of 10
Activity	of the order of 6–10 mc ^{170}Tm .

Geiger tube housing block

The Geiger tube housing block consists of a mild steel block surrounding a portion of the length of the rotameter tube. Holes are bored from two sides of the block to house the Geiger tubes, with a small diameter port connecting each to the centre hole for the flowmeter tube (Fig. 2). The spacing of these ports in relation to the active length of the tube is such that at least one Geiger tube will receive radiation as the float moves up or down the flowmeter tube.

When Geiger tubes are fitted, and the length of the housing block is such that approximately one-third of the total length of the meter tube is covered, the prototype instrument (Fig. 6), which was exhibited at the Instruments, Electronics and Automation Exhibition

at Olympia in 1960, the housing block was secured in a position to cover the centre of the range of measurement of the flowmeter tube. In use, it is intended that the block should be mounted on vertical rods, and secured in any position along the length of the tube.

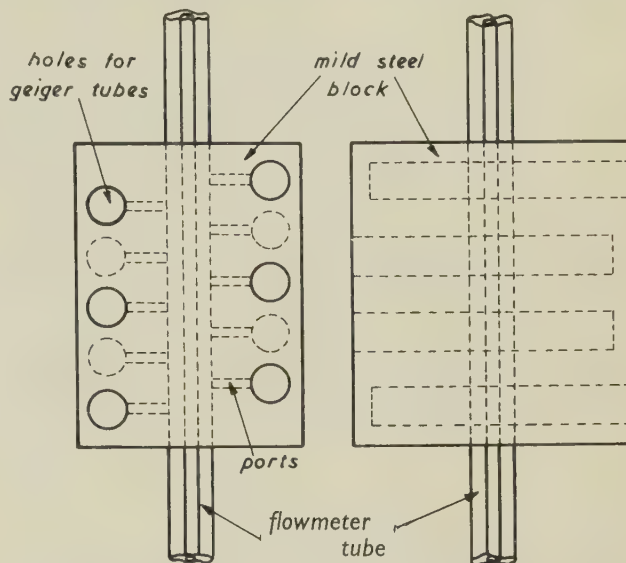


Fig. 2. Geiger tube housing block.

Basic circuit

Figure 3 shows the basic circuit associated with a single Geiger tube and its accompanying amplifier, indicating and recording stages.

With the grid of the valve biased by the battery voltage to a point where the valve is just not conducting, relay A is in the relaxed position, with contacts a_1 and a_2 open. When the radioactive float approaches the Geiger tube G, current flows in the tube circuit, and the potential across the Geiger load resistance R_L rises, causing the grid of the valve to approach the cathode potential. The valve then conducts and relay A is energized. Contacts a_1 close and the position-indicating lamp L lights. Contacts a_2 also close and the recorder input is then connected directly to the proportion of the potentiometer chain P, which gives a corresponding deflection of the recorder pen.

A permanent record and visual indication is therefore given whenever the float approaches and irradiates a Geiger tube in the system.

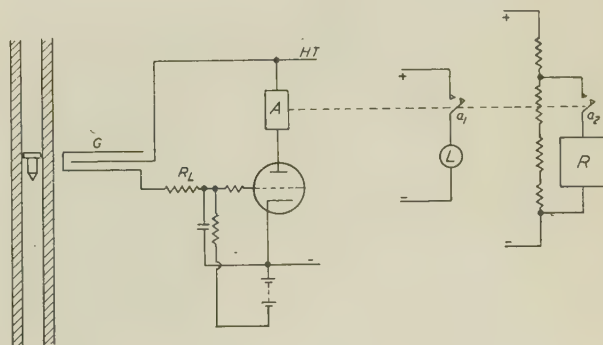


Fig. 3. Basic circuit.

Power supplies

Main amplifier stage

Where repetitive components occur in the circuit, R_4 - R_{13} , R_{14} - R_{23} , and C_3 - C_{12} , these are mounted on grooved boards to facilitate wiring and maintenance.

Recorder output stage and position indicating lamp circuit

A stabilizing valve (V_7) is used to give a constant potential supply to a potentiometric chain of ten equal resistors mounted on a group-board (Fig. 5). The junction of each resistor is tapped, via one contact of each relay, and the potential of any point selected by the operation of the corresponding Geiger tube and amplifier stage, is applied to the wire-wound potentiometer R_{57} . This potentiometer further reduces the potential to a value which can be accepted by the recorder. With the selection of any intermediate

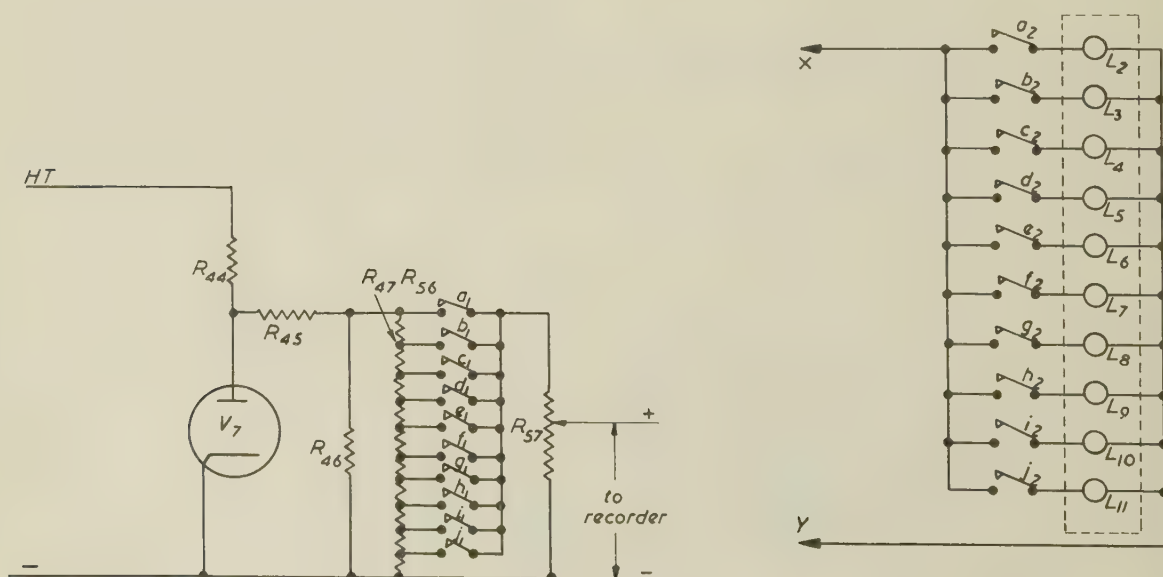


Fig. 5. Recorder output stage and position indicator lamp circuit.

the potentiometric chain, i.e. by the operation of another Geiger tube, a proportional deflection of the recorder pointer is produced.

With the operation of each relay, a second contact closes the series circuit of an indicating lamp. These lamps are mounted vertically behind a glass scale (Fig. 6), and when in operation show the position of the float within the length of the flowmeter tube surrounded by the steel block. The graduated length of the scale, compared with the length of the tube portion, makes the initial setting of the gas flow-rate easier to achieve.



Fig. 6. Prototype instrument.

It has been found in practice that it is essential to have an associated amplifier stage of each Geiger tube so biased that when the float is between two ports, two tubes are activated and the indicating lamps are lit. This ensures a steady progression in the operation of the amplifiers, i.e. that a second lamp in each case is lit before the first is extinguished. This prevents any possibility of a 'dead spot' arising with consequent interruption of the recorder trace.

Sensitivity

The flowmeter tube used in the prototype instrument has a range of 0.1 to 0.7 litres/min measured at N.T.P. The working length of the tube is about 9.5 in., and with a port spacing of 0.25 in. the minimum flow represented by the operation of two successive Geiger tubes is thus 16 cm³/min, i.e. 3% of maximum flow. If it is considered that the operation of two Geiger tubes simultaneously is representative of the float in a midway position between two ports, then the minimum flow rate which may be indicated by the instrument is 8 cm³/min, i.e. 1.5% of maximum flow.

Radiation activity level surrounding the instrument

Because of the low level of activity used, and the low intensity of the radiation, there is little radiation hazard in

the use of this instrument. When the source had an activity of 4 to 5 mc, the dose-rate at the surface of the flowmeter tube is not more than 10 mr/h falling off to less than one-fifth of this value at a distance of 3 in. Hence, while the float is inside the housing block the radiation dosage is negligible. A Perspex housing enclosing the flowmeter and Geiger tubes ensures safety at all times.

Design improvements

Improvements in the design, which should be possible, are indicated in the following paragraphs.

Extended range of measurement

The prototype instrument has the metal block housing the Geiger tubes covering only a portion of the length of the flowmeter tube. It would be advantageous to have the metal block supported on vertical rods, and the position of the block along the rods determining the range of the rotameter over which the flow rate was being metered. It would then be possible to meter the whole range of flow rates in stages at a lower cost than that of providing a block and counters to cover the whole length of the tube.

Increased life of radioactive float

The relatively short half-life period of ¹⁷⁰Tm can be a disadvantage, especially where the instrument may be installed in a large process, making access to the flowmeter difficult.

From the amount of activity which was found to be necessary in order to get stable Geiger tube operation and good resolution, it is evident that a specific activity of the order of 500 mc/g is necessary in the float filling. The saturation activity for ¹⁵⁵Eu obtained by irradiation of ¹⁵⁴Sm is 13 mc/g.

If a longer life isotope is required, it would be necessary to use fission product europium, or to prepare ¹⁴⁵Sm or ¹⁵³Gd from material electromagnetically enriched in ¹⁴⁴Sm and ¹⁵²Gd.

The instrument would then be able to function for a considerably longer period before re-irradiation of the float became necessary.

Acknowledgments

The instrument described in this paper was designed and constructed as part of the work of the Instrument Development Section of Warren Spring Laboratory, Department of Scientific and Industrial Research, and is published by permission of the Director of Warren Spring Laboratory.

The author wishes to acknowledge advice given by Dr. E. J. Gibson of the Laboratory's Radioactive Isotope Section in the choice of suitable isotopes.

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The instrument is the subject of a Patent Application No. 25815/59.

Electrolytic tank for studying the flow of liquids through tubes of various cross sections

by M. J. DENTON and S. G. LIPSON, The British Cotton Industry Research Association, Shirley Institute, Didsbury, Manchester

MS. received 1st November 1960

Abstract

Analogue methods of solving the Poisson equation in two dimensions are discussed briefly. The electrolytic tank equivalent must have a uniform current source density; an approximation to this is achieved by introducing equal currents through conductors spaced in a square lattice. As examples, the flow velocity distribution in a tube of rhombic cross section is shown, and the equivalent radii for rhombic tubes of various angles are found.

1. Introduction

EXCEPT in a few simple cases, the rate of flow of a viscous liquid through a tube of arbitrary cross section cannot be calculated analytically. The solution for a circular tube is well known as Poiseuille's law, and solutions for rectangular (Cornish 1928) and triangular (Nuttall 1954) cross sections have also been developed. Otherwise, apart from tedious numerical methods, flow rates can only be determined by experiment. The method described in this paper involves an analogy between the equations governing the flow of an ideal viscous fluid and the potential distribution in a homogeneous conducting medium.

The equation governing the viscous flow of a fluid in a uniform tube is (Lamb 1930)

$$\frac{dP}{dz} = \eta \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) \quad (1)$$

where dP/dz is the pressure gradient along the tube, η is the fluid viscosity, and v the fluid velocity at a point (x, y) , v is zero on the boundary.

Equation (1) can be written in the form

$$\nabla^2 v = 1/\eta \, dP/dz. \quad (2)$$

Soroka (1949) expressed v as the sum of two functions ϕ_1 and ϕ_2 , so that $\nabla^2 \phi_1 = 0$ and $\nabla^2 \phi_2 = 1/\eta \, dP/dz$. By choosing an easily differentiable function for ϕ_2 to satisfy the second of these equations, v can be found by solving for ϕ_1 with boundary conditions given by ϕ_2 . As $\nabla^2 \phi_1 = 0$ is Laplacian it can be solved by using an ordinary electrolytic tank with boundaries made of small insulated sections to allow the boundary potentials to be fitted to ϕ_2 . Bradfield, Hooker and Southwell (1937) were able to solve the two-dimensional Poisson equation (2) by using an electrolytic tank to perform a conformal transformation.

The disadvantage of these methods is that neither gives a direct plot of the flow velocity field. In addition, Soroka's method requires complicated boundaries with potentials which are difficult and tedious to adjust.

The present method gives a direct plot of v , and requires

only a strip of brass or copper bent to the required boundary shape.

2. Method

If a thin uniform sheet of a conducting material of two dimensional specific conductivity σ has a uniform current source density j per unit area, the equation determining the potential distribution is similar to Eqn (2):

$$\nabla^2 \phi = -j/\sigma.$$

In such a system, therefore, the potential distribution would be the same as the velocity distribution in a uniform tube the boundary of the tube being represented by a closed curve of the same shape kept at zero potential.

Unfortunately, it is impossible to reproduce experimentally a uniform continuous current input. Furthermore, the current input must be independent of the potential. The compromise adopted, suggested in the discussion following a paper by Redshaw (1949), was to use a lattice of equally spaced conductors in an electrolytic tank, each carrying the same current into the tank. A similar arrangement was adopted by Van Duzer and Brewer (1959) for the simulation of space charge in electrostatic lenses.

Some workers (Liebmann 1949, 1950, Redshaw 1949) have solved the Poisson equation using a resistance network in place of an electrolytic tank. Although a network is more robust, free from polarization and easier to manipulate, no interpolative difficulties arise with an electrolyte as it is itself an excellent interpolative medium. Also, nearly three times as many precision resistors are needed to build the equivalent resistance network.

3. Apparatus

The apparatus is shown diagrammatically in Fig. 1. The tank, constructed of wood and ebonite, was about 10 in

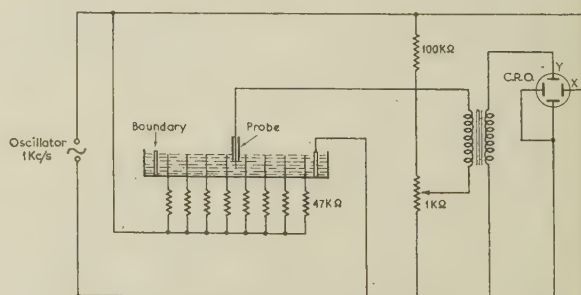


Fig. 1. Circuit diagram.

re, and had 100 input sources, which were 8 B.A. brass
screws, extending right through the solution to the surface.
screws were spaced in a square lattice, 10×10 at $\frac{1}{4}$ in.
vals and each was connected in series with a $47 \text{ k}\Omega \pm 1\%$
tor. The depth of copper sulphate electrolyte was about

The series resistance value was chosen to give the
imum tank potential consistent with the available power
the oscillator. As the maximum tank resistance was
nged to be about 1% of the external supply resistance,
condition of constant current supply to each probe was
fied to within 1%. The potential in the tank was
sured by a wire search probe immersed to about half
depth of the tank. As the input probes extended right
ugh the solution, the depth of immersion of the search
e was not at all critical.

ne probe position was plotted by means of a simple
ograph with a magnification of approximately two, this
e the plotting of equipotentials particularly easy. Pres-
s to the pantograph, the system of coordinates described
Bradfield, Hooker and Southwell (1937) was used, but
ough this gave good definition of the points, replotting
n was a long and tedious process.

relative potentials in the tank were measured by reading
n off against a calibrated $1 \text{ k}\Omega$ potentiometer in series
a $100 \text{ k}\Omega$ resistor and the 1000 c/s tank supply, the
of-balance voltage being displayed against the supply
age on a cathode-ray oscilloscope. In general the trace
an ellipse due to slight phase changes in the tank, but
ong as these phase changes were small the balance point
reached when the ellipse had its major axis horizontal.
conductivity of the electrolyte was controlled by varying
concentration, so that the maximum potential reading
about ten units on the potentiometer scale. The pre-
ions usual with electrolytic tanks were taken before
ing experiments.

4. Accuracy test

test using a circular boundary was carried out to deter-
e the error introduced by the discontinuity of the input.
mathematical solution can easily be worked out if the
dary radius and maximum potential are known, and

the radii of equipotentials can be calculated and compared
with the experimental radii. The latter were determined by
measuring the radii of equipotentials along six radius lines,
spaced at 60° intervals and taking the average (Table 1).

Table 1. Comparison between analytical and experimental results for a circular boundary

Potential (potentiometer units)	Experimental (average of six measurements)	Radii (cm) Analytical
9.0	5.8 ± 0.1	6.0
8.0	8.5 ± 0.1	8.4
7.0	10.7 ± 0.1	10.6
6.0	12.3 ± 0.1	12.3
5.0	13.90 ± 0.05	13.8
4.0	15.1 ± 0.1	15.1
3.0	16.3 ± 0.1	16.3
2.0	17.53 ± 0.05	17.4
1.0	18.6 ± 0.1	18.5
0	19.5	19.5

The good agreement between experiment and theory shows
that although the input system was coarse (only 10×10
probes) the electrolyte acts as a good interpolative medium.

5. Treatment of data

All the data obtained from experiments were contained
in equipotential diagrams, of which Fig. 2 is a typical example.
It was required to calculate the total volume flow, and hence
the radius of the equivalent circular tube.

If the boundary C enclosed an area A the equivalent radius
is given by

$$\rho = \left(\frac{8 \iint_A \phi dA}{-\pi \nabla^2 \phi} \right)^{\frac{1}{2}} \quad (4)$$

The double integral of ϕ over the area A was calculated
from the equipotential diagrams by measuring the areas
enclosed by the equipotentials with a planimeter and finding
the integral by the trapezoidal rule.

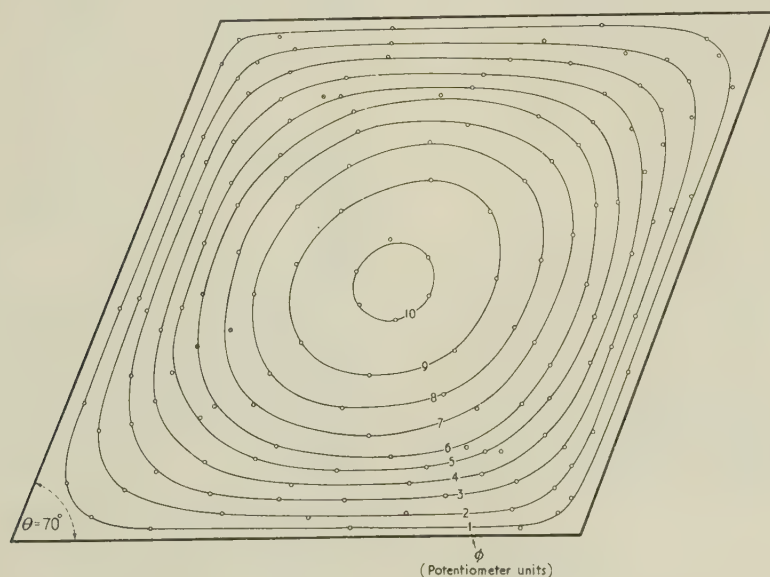


Fig. 2. Potential map of 70° rhombus.

Table 3. Computed equivalent radii of rhombi of major diagonal (25 cm)

Rhombus angle (deg)	0	10	20	30	40	45	50	60	70	80	90
Equivalent radius (cm)	0	1.92	3.21	4.35	5.35	5.90	6.30	7.13	8.00	8.85	9.65

The measurement of $\nabla^2\phi$ was a more difficult process. It could, of course, have been obtained by measuring the conductivity of the tank electrolyte and the current flowing into the probes, but the tank depth would also have to have been known accurately and it would have been necessary to measure the equipotentials in absolute volts instead of on an arbitrary scale. $\nabla^2\phi$ could, however, be obtained from the potential diagrams. A first attempt was made by measuring ϕ at a series of points on a square grid of side h and evaluating the finite difference approximation

$$\nabla^2\phi = \frac{1}{h^2} (\phi_1 + \phi_2 + \phi_3 + \phi_4 - 4\phi_0) \tag{5}$$

where ϕ_0 is the point on the lattice under consideration and ϕ_1, ϕ_2, ϕ_3 and ϕ_4 are its nearest neighbours.

However, the variation in the values obtained was unacceptable, owing to the accumulative effect of rounding off errors in the numerical differentiation process, and a more satisfactory method was required.

It was found that the transformation by Gauss's theorem in the form

$$\iint_A \nabla^2\phi dA = \oint_C \nabla\phi \cdot \mathbf{n} ds \tag{6}$$

($\mathbf{n}$ being the unit vector normal to the closed curve C bounding the region A) enabled a mean value of $\nabla^2\phi$ over a region to be calculated from the normal gradient at the boundary. This involved summing $\nabla\phi$ along the boundary of a rectangle, a much simpler matter than summing $\nabla^2\phi$ over the surface. This method gave results for which the variation in $\nabla^2\phi$ between different regions on the same map was only about 2%.

6. Results

Experiments were carried out using rhombic boundaries of fixed major diagonal and various angles, to find how the equivalent radius varied with angle (Table 2).

Table 2. Equivalent radii to rhombi of major diagonal (25 cm)

(1)	(2)	(3)	(4)
75	966	0.480	8.45
70	1045	0.699	7.85
50	620	0.905	6.45
30	264	1.64	4.50

(1) Rhombus angle (deg); (2) $\iint_A \phi dA$ (potentiometer units $\times$ cm²); (3) $-\nabla^2\phi$ (potentiometer units $\times$ cm⁻²); (4) equivalent radius ρ (cm).

The estimated experimental error in ρ was about 1%. Equivalent radii were also found for various rhombi, by solving Eqn (1), either numerically with the Manchester University computer (C. Mack, Shirley Institute internal

communication) or by relaxation methods. These results are shown in Table 3, and together with the experimental results in Fig. 3.

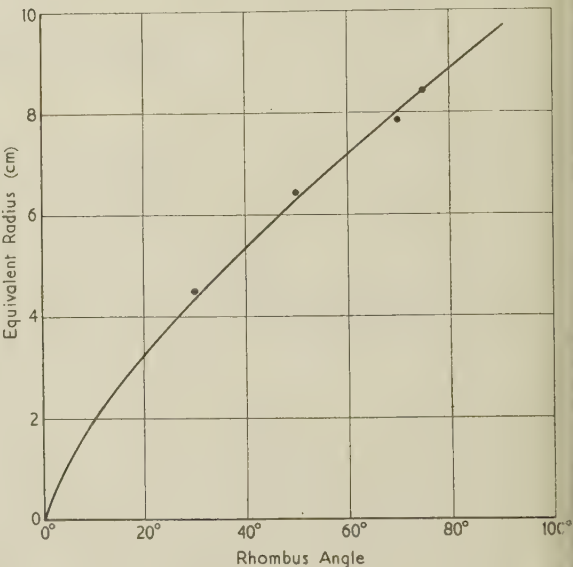


Fig. 3. Equivalent radii for steady viscous flow through rhombic tubes of various angles and major diagonal 25 cm.

7. Conclusions

Despite the coarseness and small scale of the input system to the tank the method has produced good results. If high accuracy were required it could certainly be obtained using a larger scale tank with a finer input system. As the boundaries are so easy to construct, the method can be applied to solving the two-dimensional Poisson equation for torsional stress problems as well as flow problems) in boundaries of the most complex shapes.

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X-ray diffraction data from single crystals at 20° K

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Abstract

A liquefier cryostat is used to produce the liquid hydrogen in which the crystal is cooled in situ to liquid-hydrogen temperature. This method introduces problems involving crystal cooling, crystal mounting, the rotation of the crystal and the provision of x-ray transparent windows in the cryostat walls. These are discussed, together with the preliminary results obtained with the apparatus.

Introduction

NEW measurements of x-ray diffraction data have been made on specimens, particularly rotating single-crystal specimens, at temperatures below 77° K, the boiling point of liquid nitrogen. One method of making such measurements has already been described by Robertson (1950). Our method differs from Robertson's in that it was designed for use in a laboratory where no suitable coolant, liquid hydrogen or liquid helium, was available.

The liquefier

It was decided that the simplest and most efficient way of obtaining these low temperatures was to construct a miniature Joule-Kelvin liquefier (Figgins 1957). The liquefier built produces liquid hydrogen at the rate of about 4 cm³ per minute and has a capacity of 50 cm³ of liquid hydrogen.

Methods of cooling

The fact that the liquid hydrogen is available inside the liquefier and cannot be transferred to another vessel demands a different method of crystal cooling from that normally employed when liquid nitrogen is used. Moreover, cooling by immersing the crystal in a stream of gas (Cartz 1954, Post, Schwartz and Fankuchen 1951) from the boiling refrigerant by bathing the crystal in liquid refrigerant (Lonsdale and Smith 1941) is not suitable when only a small quantity of coolant is available. Conduction cooling, used extensively for powder specimens (Barrett 1956), is not suitable for single crystals. To obtain clean x-ray photographs a single crystal must be mounted on a fibre, which is normally a poor thermal conductor.

The method decided upon used hydrogen as an exchange gas for cooling the crystal. The crystal is set up in the specimen chamber (Fig. 1) which is below the hydrogen can A of the liquefier. A low-pressure stream of hydrogen gas, supplied by liquid hydrogen, is passed through the specimen chamber B in which the crystal is enclosed. This is shown in more detail in Fig. 2.

This method of cooling is particularly efficient at low temperatures as the thermal capacity of the hydrogen gas is

enhanced relative to the thermal capacity of the metallic cryostat.

Construction of the cryostat

The liquefier cryostat has to be surrounded both by a vacuum and by copper thermal-radiation shields so that the refrigerant may be produced and retained.

(a) Windows

Windows, transparent to x-rays, must be inserted in the thermal radiation shields (Fig. 3(a)). Those in the outer shield and in the specimen can wall B must be vacuum-tight, the latter at 20° K. Metallic windows, e.g. aluminium or

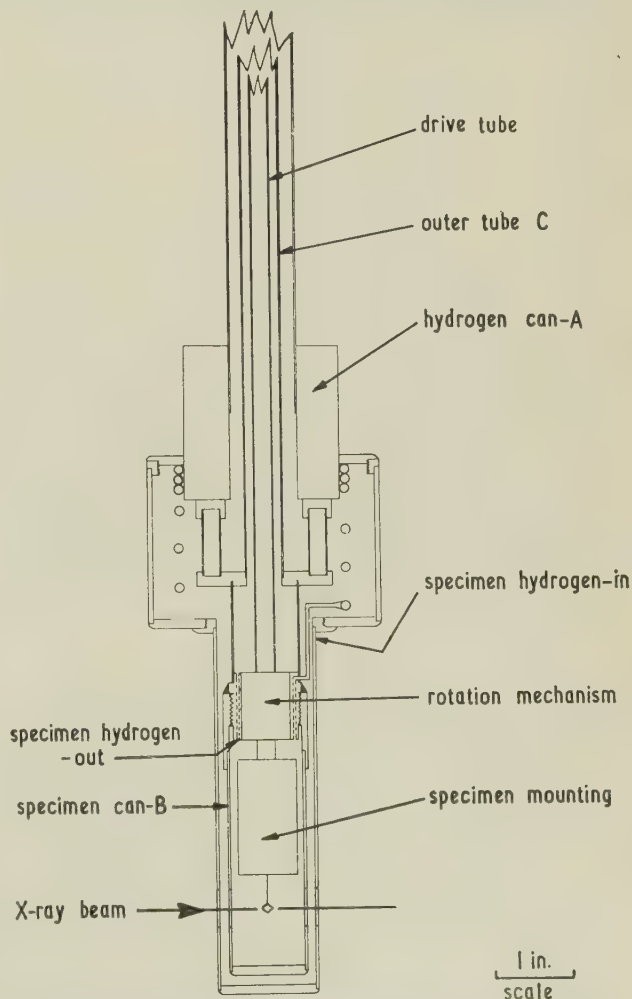


Fig. 1. General layout of lower end of liquefier and specimen can.

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beryllium, of a thickness to be strong enough and free of pinholes would absorb a prohibitive fraction of the x-ray intensity. Two materials extensively used at low temperatures successfully solved this problem. A Melinex (polyethylene terephthalate) transparent sheet 3 thou. thick clamped in place and sealed with an Araldite epoxy-resin adhesive made a highly satisfactory window.

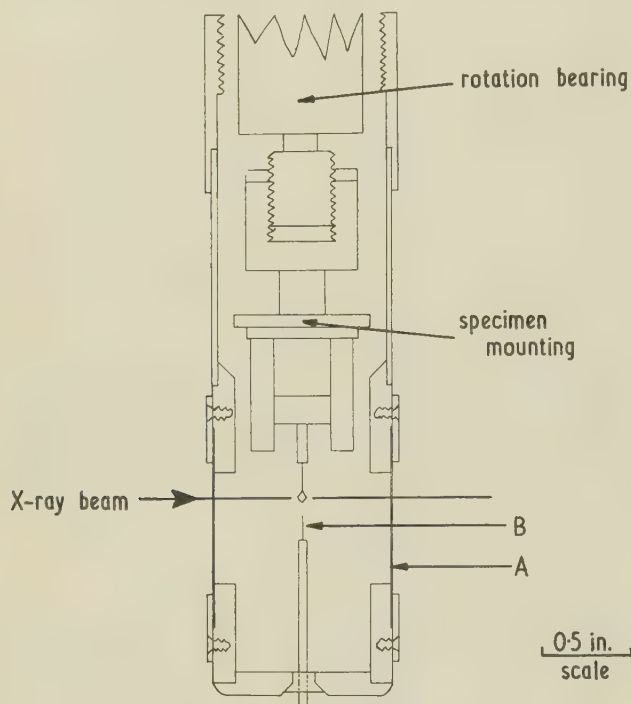


Fig. 2. The specimen can.

The specimen can window has withstood about fifty coolings to 20° K without any adverse effects. The windows in the other two shields, C, D, do not have to be vacuum-tight and are therefore made of one-third thou. thick aluminium foil (x-ray transmission 90%) with holes E, F provided for the direct beam and for viewing the specimen.

The arrangement of the windows allows for the collection of diffracted x-ray beams through a vertical angle of 10° above to 45° below the x-ray beam and through a horizontal angle of about 300° as is seen in Fig. 3(a). Supporting pillars G must be left in and these can be arranged to suit the investigation in hand, e.g. to give high angle spots in particular, or to give complete coverage of 180°, etc.

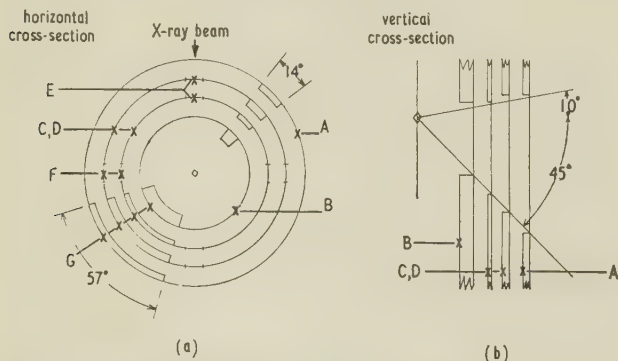


Fig. 3. The arrangement of the x-ray transparent windows: (a) horizontal cross section; (b) vertical cross section.

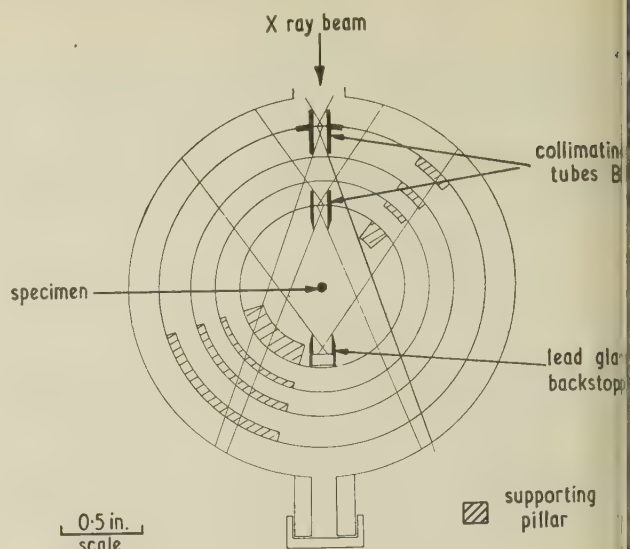


Fig. 4. The arrangement of the screening tubes and the backstop.

The scattering of the x-ray beam by one thickness Melinex is not great, but the beam passes through several thicknesses in the apparatus, and the scattering becomes considerable for exposures of 2 to 3 hours (Fig. 5(b)). The scattering is reduced by inserting: (a) a lead-glass backstop (Fig. 4) which cuts out all scattering by the direct beam after it has passed the crystal; (b) several collimating tubes which reduce the scattering by the incident beam.

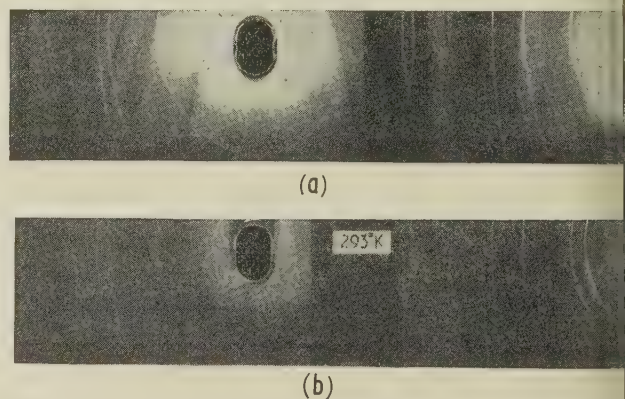


Fig. 5. X-ray photographs of aluminium taken with copper radiation: (a) without screening tubes; (b) with screening tubes.

(b) Rotation

The only x-ray photographs obtainable with a stationary crystal are Laue photographs which are of limited use in structure work. A method of rotating the crystal would be highly desirable. Any rotation mechanism has to work at both room temperature and at 20° K without any slippage or precession. After several trials, a bearing of brass and fluon was found to be suitable. This consists of a brass drive shaft A (Fig. 6) mounted in four fluon bushes. At room temperature, the shaft runs in two of these bushes B, C, which are made a tight fit at this temperature, the other two bushes D, E being quite slack. As the temperature falls, the two tight-fitting bushes contract and seize on the shaft as the coefficient of thermal expansion of fluon

greater than that of brass. The two slack-fittings also contract, but only to make a tight-fitting bearing. The bearing now consists of the shaft plus the two room-temperature bushes all as one unit, running in the two temperature bushes which are pinned so that they do rotate. The whole bearing is lubricated with graphite driven by a shaft running from a 1 rev/min motor at top of the liquefier.

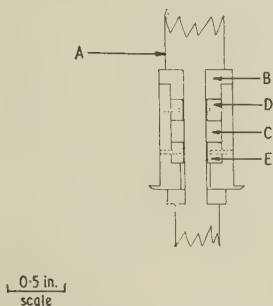


Fig. 6. The rotation mechanism.

The rotation bearing was tested by observing visually an aluminium wire specimen of known diameter and it was found that the maximum precession both at room temperature and at 20° K was 0.003°.

To retain the liquefier vacuum, the specimen can has to be hydrogen-tight. The bearing must also be hydrogen-tight. The bearing forms part of the can wall. This is virtually impossible to achieve at 20° K and so the bearing and the drive shaft are sealed with a second tube C (Fig. 1) and the hydrogen-joint made by an 'O' ring seal at room temperature at top of the liquefier.

General performance of the liquefier cryostat

The construction of the liquefier cryostat is such that any specimen must be set up before liquefaction is started as the cryostat is inside the liquefier vacuum. No further adjustments to the specimen are then possible, although the specimen is visible throughout. The cryostat is of 2 in. inside diameter and will thus fit inside a standard 3 cm film holder. The crystal is, however, mounted independently of the goniometer and the whole cryostat can be moved to readjust the crystal position. Adjustments are provided to do this.

(a) Cooling times

About six hours is required to produce liquid hydrogen if the specimen has been set up and the cryostat sealed. The usual procedure is to set up the specimen one day, leave the backing pump to evacuate the system overnight and then perform a run the next day. Once liquid hydrogen has been produced it takes about 40 minutes to cool the specimen to 20° K. When once the specimen is at this temperature, the flow in the low-pressure hydrogen circuit is turned right down and the 50 cm³ of liquid hydrogen in the can lasts for about 2½ hours. The can may then be refilled in about 15 minutes without disturbing the crystal.

(b) Temperature

The temperature reached is 20° K as measured by a copper-constantan thermocouple calibrated at 20, 77 and 195° K and having an accuracy to ±2° K at 20° K. The thermo-

couple is placed adjacent to the crystal B (Fig. 2) and so records the specimen temperature accurately.

(c) Photographs

As yet, only random-orientation rotation photographs have been taken at temperatures of 20, 80 and 290° K. These are shown in Fig. 7. The crystal tends to mis-set somewhat

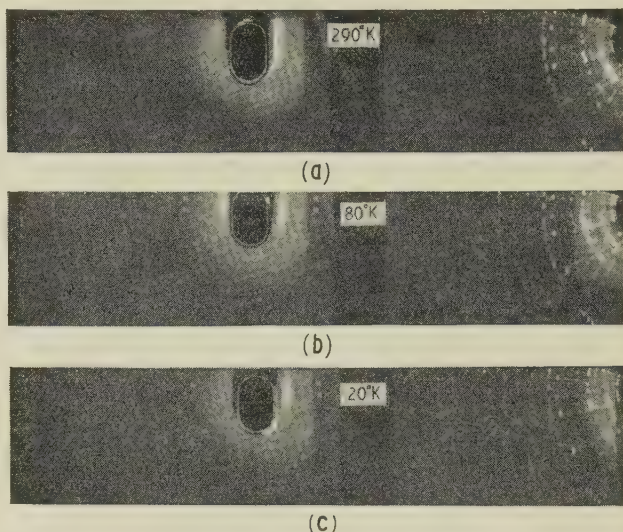


Fig. 7. Random-orientation rotation photographs of hexamethylene tetramine taken with copper radiation: (a) at 290° K; (b) at 80° K; (c) at 20° K.

on cooling owing to differential thermal contraction of the mounting and to the drying out of the adhesive. This makes set rotation photographs rather more difficult to obtain.

(d) Developments

Two main developments of the apparatus are foreseen. One is to incorporate a heater on the specimen can so that further intermediate temperatures in the range 20 to 290° K can be obtained.

Secondly, it is hoped to produce either oscillation or moving-film photographs. As the drive shaft is about 3 ft long any oscillation technique which involves reversal of the direction of rotation is impracticable owing to the great backlash in the drive and some beam chopping method would be required.

Preliminary results

Random-orientation rotation photographs of hexamethylene tetramine and urea single crystals, and a set rotation photograph of aluminium wire, have been obtained at the three temperatures 20, 80 and 290° K. Lattice spacings have been calculated for all three substances and diffraction intensities measured for the single crystals. As yet, the measurements are only from one specimen of each substance and usually from a different film for each temperature. Attempts to obtain several exposures on the same film have met with some success, thus improving the accuracy of comparison of the spacing measurements at different temperatures. All spacing measurements were made from high-angle reflections. From these measurements, it was found that there is quite a definite and detectable difference

in both the lattice dimensions and the diffraction intensities as the temperature falls from 80 to 20° K.

Acknowledgments

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Technique using ⁸⁵Kr-labelled krypton for surface area measurements

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Abstract

A simple volumetric apparatus for the determination of the surface area of solid materials is described. Isotopically labelled krypton (⁸⁵Kr) is used as the adsorbate and the pressure measured using a combined counting cell and Geiger-Müller tube. The apparatus can be used to measure areas of 0.01 m² to 1 m² with a precision to 5% for 0.025 m², 1% for 0.1 m² and 1.5% for 1 m².

1. Introduction

AS sorption is probably the most widely used technique for the measurement of the surface area of solid materials, the amount of gas adsorbed as a function of pressure being determined (Gregg 1951) either gravimetrically or volumetrically and the surface area calculated from the adsorption isotherm by the method of Brunauer, Emmett and Teller (1938). For small areas (up to 1 m²) the volumetric method is particularly suitable with krypton as the adsorbate (Beebe, Beckwith and Honig 1945) since, at the temperature of boiling nitrogen (78° K) the saturation vapour pressure of krypton is only 2 mm, so that the proportion of gas unadsorbed relative to that adsorbed is small. Perhaps the most generally used pressure-measuring device is the McLeod gauge, although the use (Rosenberg 1956) of a thermal conductivity gauge embodying a thermistor has attracted some interest.

A recent study (Aylmore and Jepson, to be published) of the formation of porous oxides on a number of metals during oxidation at elevated temperatures necessitated the determination of some 150 surface areas of partially oxidized metal specimens, the values varying from 200 cm² to 5000 cm².

Previous experience has shown that a McLeod gauge has certain disadvantages for pressure measurement: it is fatiguing to use, considerable computation is necessary in converting the readings to actual pressure and errors (Leck 1957) can arise because of the variable mercury-glass contact and particularly when the mercury has become contaminated. These considerations led to the development of a simple volumetric apparatus using ⁸⁵Kr-labelled krypton, where the pressure could be measured by means of a combined counting cell and Geiger-Müller tube.

2. Principle of the method

The krypton was isotopically labelled with ⁸⁵Kr (half-life 10.6 years) and the pressure measuring device (Fig. 1) consisted of a counting cell C (volume, 4 cm³) sealed on to an end-window Geiger-Müller tube D (modified EW3 counter, by 20th Century Electronics Ltd.). Since self-absorption in the gas was negligible (maximum pressure was 1.72 mm), the count rate N , after correction for counting losses and background (Taylor 1951), is proportional to the pressure of krypton p so that

$$p = \alpha NT$$

where T is the temperature (of C). The calibration factor α is a constant for the apparatus and a particular batch of krypton (radioactive decay only produces a change of 1% in α in about two months); its value is conveniently determined by measuring the count rate given by the saturation vapour pressure of krypton (Keesom, Mazur and Meihuizen 1935) at the temperature of boiling nitrogen, as measured on an oxygen vapour pressure thermometer (Farkas and Melville 1939) (to ± 0.05 deg c).

For all measurements, excluding those of the saturation vapour pressure, 10^4 counts were made to give a standard error in the counting rate of $\pm 1\%$; this meant that

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tures were measured to this same precision regardless of their absolute value. For measurements of the saturation vapour pressure, 4×10^4 counts were made to give a standard error of $\pm 0.5\%$. It should be realized that whilst the use of high specific activity will shorten the time to carry out a measurement, the counting losses (the paralysis time of the electronic equipment was $500 \mu\text{s}$) increase with counting rate. In the present work the maximum count rate was 120 counts/s so that correction for counting losses did not exceed 6.5% .

The amount of krypton adsorbed by the sample was determined volumetrically and the apparatus (Fig. 1) was designed to measure absolute areas in the range 0.01 to 1.0 m^2 . For the measurement of an area less than 0.1 m^2 , bulbs 5 to 8 remain filled with mercury during the run.

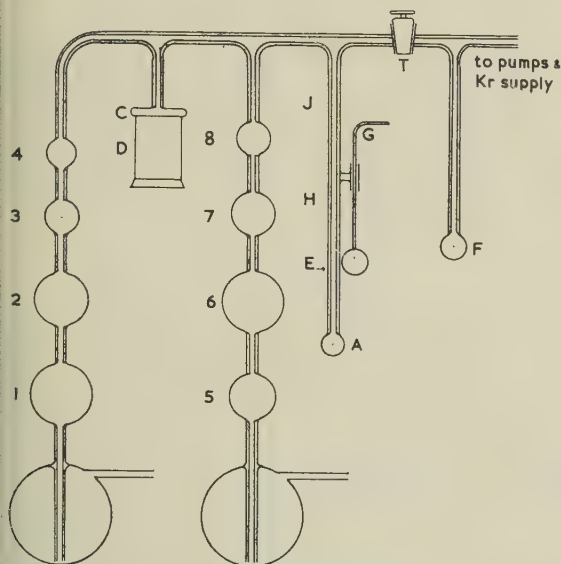


Fig. 1. The adsorption apparatus.

the first point on the adsorption isotherm is obtained by immersing the sample bulb A in liquid nitrogen; further points are then measured by progressively filling the bulbs 1 to 4 with mercury, giving, in all, five experimental points on the isotherm. For an area greater than 0.1 m^2 , the procedure is the same except that all the bulbs are used, the sequence of filling being all bulbs from 1 to 5, followed by 6 and 8. The volumes of the bulbs (Table 1) for the two

Table 1. The volumes of the bulbs

Bulb	Volume (cm^3)	Bulb	Volume (cm^3)
1	58.3	5	20.7
2	31.6	6	53.2
3	8.6	7	14.8
4	4.3	8	7.4

gas pressures were chosen so as to give points on the adsorption isotherm at relative pressures between 0.025 and 0.25 for maximum absolute areas of 0.01 m^2 and 0.1 m^2 respectively. Figure 2 illustrates how the range of the isotherm covered by a particular run diminishes as the area of the sample is increased.

An important feature of the method is that the amount of gas (adsorbed and unadsorbed) in the apparatus is constant throughout a determination of the isotherm, so that the accumulation of errors normally associated with the method of successive runs does not occur.

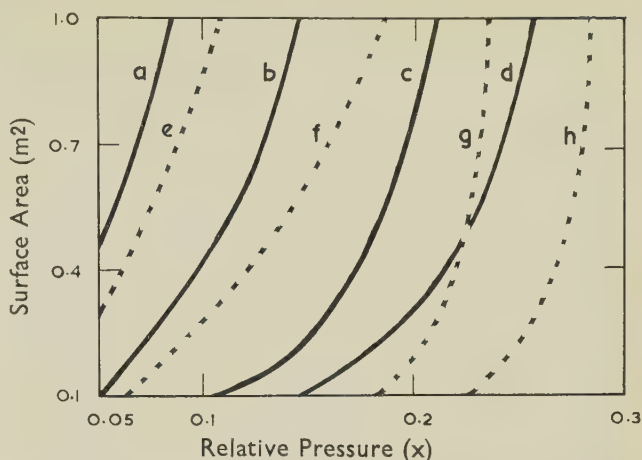


Fig. 2. Showing the range of the isotherm covered by the adsorption apparatus for areas between 0.1 and 1.0 m^2 . Curves *a* to *d* (unbroken) give the values of the relative pressures x_0 to x_3 obtained, for various values of S , by filling the bulbs in the sequence 1 to 5, followed by 6, 7 and 8, the last point x_4 being fixed at 0.25 . Curves *e* to *h* (broken) show the same but with the last point on the isotherm x_4 fixed at 0.30 .

3. Experimental

The radioactive krypton was obtained as a purified fission product (0.22 cm^3 of gas at N.T.P. with a total activity of 12.8 mCi ; Atomic Energy Research Establishment, Harwell) and was diluted with about 4 l. of spectroscopically pure krypton (99%, balance xenon) to give a gas of specific activity $3 \mu\text{Ci}/\text{cm}^3$ at N.T.P., yielding a count rate of 120 counts/s at 1.7 mm pressure. Because of the large dilution factor the impurities present in the active krypton were reduced to concentrations of less than 1 part per million, except for nitrogen (together with carbon monoxide) for which the concentration was 2.5 p.p.m.

3.1 Calibration

Before the apparatus was assembled, the bulbs were calibrated by filling each column with mercury and successively emptying the contents of each bulb into a flask and weighing. The volume of each bulb was measured to $\pm 0.01 \text{ cm}^3$, so that any error from this source in the surface area was negligible.

After the apparatus had been constructed, the volume of the dead space (the volume of the apparatus less that of the bulbs 1 to 8 and to the standard mark E, Fig. 1) was determined. For this purpose, a charge of krypton was admitted and after closing tap T the count rate was measured, first with all bulbs filled with mercury and then with bulbs 6, 7 and 8 emptied. The volume of the short length of capillary tubing, which had of necessity to be retained below E, was estimated geometrically and subtraction of this from the calculated volume gave V_d , the volume of the dead space.

3.2 The range 0.01 m^2 to 0.1 m^2

At the start of a run, the sample container A is sealed on to the apparatus below the mark E. After evacuating the apparatus* and outgassing the sample, the bulbs are filled

* Because of the fragile mica window in the counter, the apparatus must be evacuated slowly; similarly, at the end of a run, air must be slowly admitted through a fine capillary tube.

with mercury and a small amount of krypton is condensed from the storage bulb (not shown) into the bulb F, which is immersed in liquid nitrogen. (It was found necessary throughout to bubble a slow stream of gaseous nitrogen through the liquid nitrogen to prevent supercooling.) After measuring the count rate corresponding to the saturation vapour pressure, tap T is closed, bulbs 2, 3 and 4 are emptied and the count rate again measured; this enables the volume of the total dead space $V_d + V$ and hence that of the sample container, V , to be calculated. Bulbs 2, 3 and 4 are refilled and the appropriate charge of krypton admitted (see Appendix), tap T is finally closed and, after emptying the mercury from bulbs 2, 3 and 4, the count rate is measured. (It is necessary to expand the gas for this measurement so that the uncertainty in the volume of the dead space, about 0.1 cm^3 , is negligible for the purpose of calculating the initial amount of gas.) Bulb 1 is then emptied of mercury and the bulb A containing the solid is immersed in liquid nitrogen to the standard mark E, the liquid level being easily maintained by the float G. When equilibrium is reached, as indicated by a 'constant' count rate, the latter is measured and successive points on the isotherm are measured.

3.3 The range 0.1 m^2 to 1.0 m^2

The procedure is similar to that described above, except that all eight bulbs are used in determining the isotherm; the correct charge of krypton (see Appendix) is now conveniently admitted by emptying the appropriate bulbs (there are 25 combinations) and exposing to the saturation vapour pressure.

4. Calculation of results

Because of thermomolecular flow, the pressure p' of krypton in equilibrium with the adsorbent is not the same as the pressure p in the counting cell; the two are related by the expression

$$p' = fp \quad (2)$$

where f is a function of pressure. The value of f depends on the diameter of the capillary tube H (in the present work, 2 mm) and can be calculated from the formula proposed by Liang (1953, 1955) and subsequently verified by Rosenberg (1956).

The volume of gas Δv_j (expressed as cm^3 at N.T.P.) adsorbed at a relative pressure x_j is given by the relation

$$\Delta v_j(x_j) = k \left\{ \frac{N_i}{100}(V_i + V) - \frac{N_j}{100}(V_j + f \frac{T_j}{T_N} V) \right\} \quad (3)$$

$$x_j = \frac{f}{\beta} \frac{N_j}{N_0} \frac{T_j}{T_0} \quad (4)$$

where $V_i + V$ = volume of apparatus at dosing; V = volume of apparatus immersed in liquid nitrogen; V_j = volume of apparatus at the j th determination, excluding V ; k = calibration constant of the apparatus, given by $273 \times 100 \times (\alpha/760)$ with p in mm and volumes in cm^3 ; T_N = boiling point of liquid nitrogen at atmospheric pressure (in the present work, 77.3°K); N_i = corrected count rate at dosing and room temperature T_i ; N_j = corrected count rate at the j th determination and room temperature T_j ; N_0 = corrected count rate corresponding to the saturation vapour pressure at T_N and room temperature T_0 ; β = the ratio of the saturation vapour pressure of supercooled liquid krypton (Meihuizen and Crommelin 1937) to that of solid krypton (Keesom,

Mazur and Meihuizen 1935) at T_N . β has a value of 1.0 at 78°K .

In Eqn (3) the factor of 100 is inserted for ease of computation and the coefficient β is used following the suggestion of Beebe, Beckwith and Honig (1945) that the relative pressure x should involve the saturation vapour pressure of supercooled liquid krypton rather than that of solid krypton.

The surface area S of the sample is calculated from the values of Δv_j and x_j by the method of Brunauer, Emmett and Teller (1938) using the relation

$$\frac{x_j}{\Delta v_j(1 - x_j)} = \frac{1}{v_m C} + \frac{C - 1}{v_m C} x_j \quad (5)$$

and

$$S = \frac{v_m}{v} N A_m \quad (5b)$$

where v_m is the monolayer capacity, C is a constant which depends upon the particular adsorbate-adsorbent system, v is the volume of one mole of krypton at N.T.P., N is Avogadro's number and A_m is the area of the adsorbable krypton molecule for which a value of $19.5\text{ \AA}^2$ is used (Beebe, Beckwith and Honig 1945). Eqn (5b) is valid over the range $0.05 \leq x_j \leq 0.35$.

5. Discussion

With the two apparatuses constructed for the present studies, and using material with a relatively small internal surface so that equilibrium was reached within a period of about 10 min, two areas could be determined in about 30 min (excluding the time taken to outgas the sample). The surface area can be evaluated from the numerical data in about 10 min with a desk calculating machine.

Both the reproducibility and the consistency of the apparatus were checked by making five determinations of the surface area of a sample of iron oxide, using absolute areas of approximately 0.025 (A) , 0.1 (B) and $1\text{ m}^2\text{ (C)}$ respectively. The reproducibility is seen from Table 2.

Table 2. Values for the surface area of iron oxide

	Sample		
	A	B	C
Absolute area (m^2)	0.0239	0.144 ₅	0.967 ₂
	0.0262	0.145 ₆	0.962 ₃
	0.0227	0.144 ₆	0.945 ₅
	0.0236	0.146 ₀	0.931 ₇
	0.0247	0.148 ₃	0.950 ₈
Mean value (m^2)	0.0247	0.145 ₈	0.951 ₅
Standard deviation (%)	5	0.9	1.4
Specific surface area (m^2/g)	1.48	1.240	1.236

be satisfactory, and the mean values of the specific surface area (surface area per gramme) for the 0.1 m^2 and 1 m^2 samples are in close agreement; the value for the 0.025 m^2 sample appears high because the area of the glass bulb itself is no longer negligible.

The method requires that the approximate area of the sample be known in order that the correct dosage of krypton is made; if this should be unknown a trial experiment is easily made.

Finally, the use of isotopically labelled gas is particularly

ed for the study of adsorption at low coverages, since pressure can be measured to $\pm 1\%$ regardless of its absolute value. For such an application, the method of successive dosing must be used and the apparatus modified introducing a tap at J in Fig. 1; the correction for the amount of gas unadsorbed is now small because of the low pressures used and any additional errors from this source negligible. Fig. 3 shows an isotherm for the adsorption

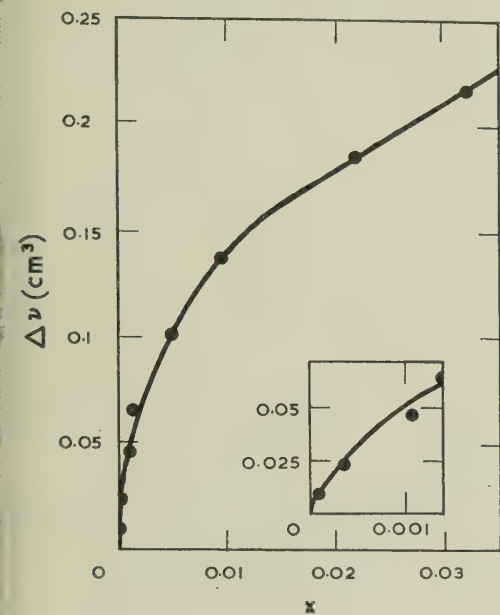


Fig. 3. Showing the isotherm for the adsorption of krypton at low coverages. The volume of krypton adsorbed per gram Δv (in cm^3 at N.T.P.) is plotted against the relative pressure x .

krypton on iron oxide at relative pressures in the range 0.01–0.03, the data of Kington and Holmes (1953) having been used for thermomolecular flow corrections.

Acknowledgments

It is a pleasure to thank Dr. S. J. Gregg for his continued interest and encouragement, Mr. J. A. Baker for assistance with the experimental work and Mr. M. Gibson for the preparation of the sample of iron oxide. We are also grateful to the United Kingdom Atomic Energy Authority for the financial support which they have given to this work, which forms part of a general programme on the oxidation of metals.

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Appendix

If the approximate area of the sample be known, the charge of krypton appropriate for the determination can be read off from a calibration curve of N_i against S which is derived as follows. Neglecting the term $1/\nu_m C$ in Eqn (5), we have the approximate relation

$$(1 - x_j)\Delta v_j = 0.189 S \quad (6)$$

while for all bulbs filled with mercury, Eqn (3) becomes

$$\Delta v_j(x_j) = k \left\{ \frac{N_i}{100}(V_i + V) - \frac{N_j}{100}(V_d + 4V) \right\} \quad (7)$$

having put $f = 1$ and $T_j/T_N = 4$. To the same approximation, Eqn (4) becomes

$$x_j = \frac{1}{\beta} \frac{N_j}{N_0} \quad (8)$$

If the last point on the isotherm, x_4 , is fixed at 0.25, elimination of Δv_j from Eqns (6) and (7) gives, after using Eqn (8), a relation of the form

$$N_i = aS + b \quad (9)$$

where a and b are easily derived constants.

A temperature compensated magnetizing coil

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MS. received 19th December 1960

Introduction

A need recently arose for a coil system such that the small magnetic field due to the coil was accurately proportional to the potential difference applied across it. The change in resistivity with temperature of a simple coil system does of course produce a deviation from this linear relationship. This problem has an interesting parallel with that of producing a pendulum whose period is unaffected by changes in the ambient temperature.

The most straightforward solution, corresponding to using invar for the pendulum, is to use an alloy with a very low temperature coefficient of resistance such as manganin, but a high resistivity material has obvious disadvantages. Another solution, analogous to that used by Harrison in his compensated pendulum, is to use two coils wound with wires of differing temperature coefficients of resistance and connecting the coils in parallel so that their fields oppose each other.

To illustrate the application of this principle, consider the very simple case of a solenoid wound with a single layer of two metal tapes 1 and 2, each of thickness T , laid side by side. The width of tape 1, which comprises the magnetizing coil, is F and that of the other, which comprises the compensating coil, is $1 - F$. If the applied potential difference is E , then the net field in the solenoid is given by

$$H_1 - H_2 = \frac{2ET}{r} \left\{ \frac{F}{\rho_1(1 + \alpha_1 t)} - \frac{1 - F}{\rho_2(1 + \alpha_2 t)} \right\}$$

where r is the mean radius of the solenoid and the other symbols have their conventional significance. Since α is very small

$$H_1 - H_2 = \frac{2ET}{r} \left[\left(\frac{F}{\rho_1} - \frac{1 - F}{\rho_2} \right) - t \left\{ \frac{F\alpha_1}{\rho_1} - \frac{(1 - F)\alpha_2}{\rho_2} \right\} \right]$$

If $H_1 - H_2$ is to be invariant with temperature then

$$F\alpha_1/\rho_1 = (1 - F)\alpha_2/\rho_2 \tag{1}$$

and if this condition is satisfied then

$$H_1 - H_2 = 2ETF(1 - \alpha_1/\alpha_2)/r\rho_1. \tag{2}$$

If the solenoid were entirely of metal 1 the field in it would be

$$H \simeq 2ET/r\rho_1 \tag{3}$$

so that

$$(H_1 - H_2)/H \simeq F(1 - \alpha_1/\alpha_2).$$

The design of a temperature compensated coil

In designing a practical combination of coils it is necessary that Eqn (1) be satisfied without lowering unduly the resultant field $H_1 - H_2$ compared with the original uncompensated field H of Eqn (3). If $H_1 - H_2$ is to be large then from Eqn (2), α_1/α_2 must be small and F must be close to 1. From Eqn (1) it may be seen that if this is to be the case then α_1/ρ_1 must be small compared with α_2/ρ_2 . If H itself is to be large then ρ_1 must be small, and so ρ_2 must be small also.

From the table of values of α and ρ it would seem that a suitable combination is a coil of brass with a compensating coil of copper. Then from Eqn (1), taking ρ (brass) : 6×10^{-6} ohm cm, it is found that $F = 0.935$. The relative fields produced for a given potential difference by coils of the same dimensions constructed of various materials are: copper 1.00, brass 0.29, compensated 0.21, and manganin 0.040.

So far, the number of compensating turns has been assumed to be equal to the number of magnetizing turns. This need not be the case, and a more general relationship is easily deduced. A multilayer solenoid is probably best constructed by winding many layers of brass wire interspersed by a few layers of copper wire: the wires must not contain any ferromagnetic impurities.

It must be remembered that the resistance of the coil will still be a function of its temperature, so that if the field due to the coil is required to be invariant with temperature the coil must be connected to a low impedance source.

Acknowledgments

The author would like to thank the management of Mullard Research Laboratories for permission to publish this Note and Dr. F. W. Harrison for a helpful discussion.

The table is based upon those in *Physical and Chemical Constants* by G. W. C. Kaye and T. H. Laby with the permission of the publishers, Longmans, Green and Co.

α is the temperature coefficient of resistance.
 ρ is the resistivity in ohm cm.

	$\alpha \times 10^4$	$\rho \times 10^6$	$\alpha/\rho \times 10^{-2}$
Aluminium	38	3.21	11.8
Bismuth	42	119.0	0.353
Cadmium	40	7.54	5.30
Copper, drawn	42.8	1.78	24.0
Gold	40	2.42	16.5
Lead	43	20.8	2.03
Palladium	37	10.7	3.46
Platinum	38	11.0	3.43
Molybdenum	50	4.8	10.4
Silver	40	1.63	24.5
Tantalum	33	14.6	2.26
Tin	45	11.3	4.01
Tungsten	51	5.5	9.27
Zinc	37	6.1	6.06

Alloys

Brass	10	6.9	1.66-1.11
Manganin	0.02-0.5	44.5	0.0045-0.011
Platinoid	2.5	34.4	0.0727
Nichrome	1.7	110	0.0154

id nitrogen cryostat for electrical measurements on crystal samples in magnetic and light fluxes

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MS. received 19th September 1960, in revised form 29th October 1960

crystostat was designed for making photomagnetic measurements on crystal samples with sizes of the order $10\text{ mm} \times n \times 1\text{ mm}$. It can also be used for magnetoresistive and conductive measurements. It has the following features:

the crystal temperature can be continuously varied from about 77°K to about 330°K and held at any intermediate temperature, several electrical connections can be made to the crystal, the crystal is easily accessible when in position, the Dewar vessel does not pass between the pole pieces, the light path to the crystal is 6 cm and the optical window has a diameter of 4.5 cm.

The cryostat is used in conjunction with a rotatable electro-magnet mounted with the plane of its yoke horizontal. The line of centres of the pole pieces is as shown broken in the Figure. The cryostat consists of a vertical copper rod, G, 30 cm long and 5 mm in diameter contained in a cylinder, A C, of 4 cm in diameter which is evacuated through E. The lowest end of the rod is always immersed in liquid nitrogen; the temperature of the highest end K, to which the crystal is clamped, is varied by means of the heater H. The temperature of the under side of the crystal is measured with a copper-constantan thermocouple embedded in the top of the rod. The uniformity of the temperature of the crystal is determined by its thickness, emissivity and thermal conductivity; for a crystal 1 mm thick with an emissivity of 0.5 the thermal conductivity would have to be $5 \times 10^{-4}\text{ cal sec}^{-1}\text{ cm}^{-1}\text{ deg}^{-1}$ to produce a temperature difference due to absorbed radiation of 1° at 77°K between its upper and lower surfaces. An 8 watt heater gives a maximum warming rate of 13° per min. and a maximum steady temperature of 230°K . For a fixed temperature of the rod the upper surface of the crystal decays to equilibrium with a time constant equal to the product of its thermal resistance and thermal capacitance; for a crystal with mass 0.5 gm , area 0.5 cm^2 , specific heat 0.5 and the above thickness and thermal capacity the time constant is of the order of 100 seconds. J is a Perspex block which supports the electrical leads and to which a crystal clamping plate is screwed. The cylinder is constructed in two parts: the brass section A, which includes the optical window, can be removed; the lower section C is made from stainless steel tubing (BS Spec. S.110) and nitrogen losses due to conduction down it amount to only a few cc per hour.

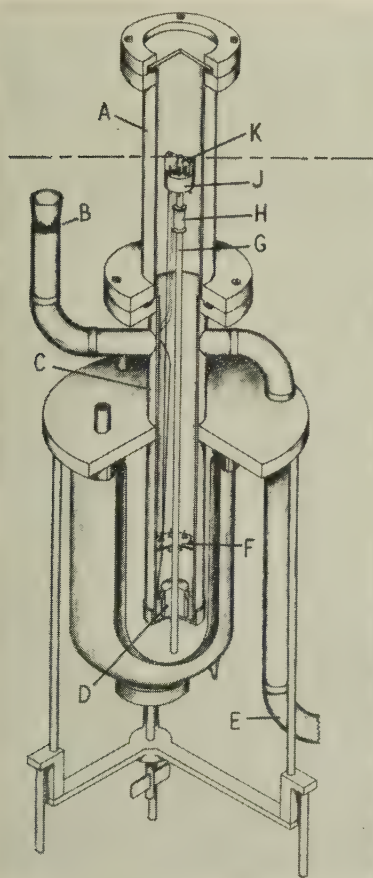
Two heater leads and four leads to the crystal pass through the supporting disk F (each in a commercial vacuum seal) and leave at the glass cone joint B. To prevent heat leaks the leads are thermally connected to the nitrogen cooled copper cylinder D but electrically insulated from it with 'Supermex'. The optical window is pierced by two sealed tubes (not shown in Figure) of internal diameter 2 mm and external diameter 6 mm offset along the line of centres of the pole pieces. One admits the leads of a radiation thermocouple with a copper-'Brightray' junction, the other contains a weak solution of manganese sulphate and carries the radio frequency coil (with the perpendicular to its axis collinear with the line of centres) of a modified Hopkins circuit (Hopkins 1949) used to measure the magnetic field by means of the proton resonance. The lead to the oscillator is brought through A in a commercial vacuum seal.

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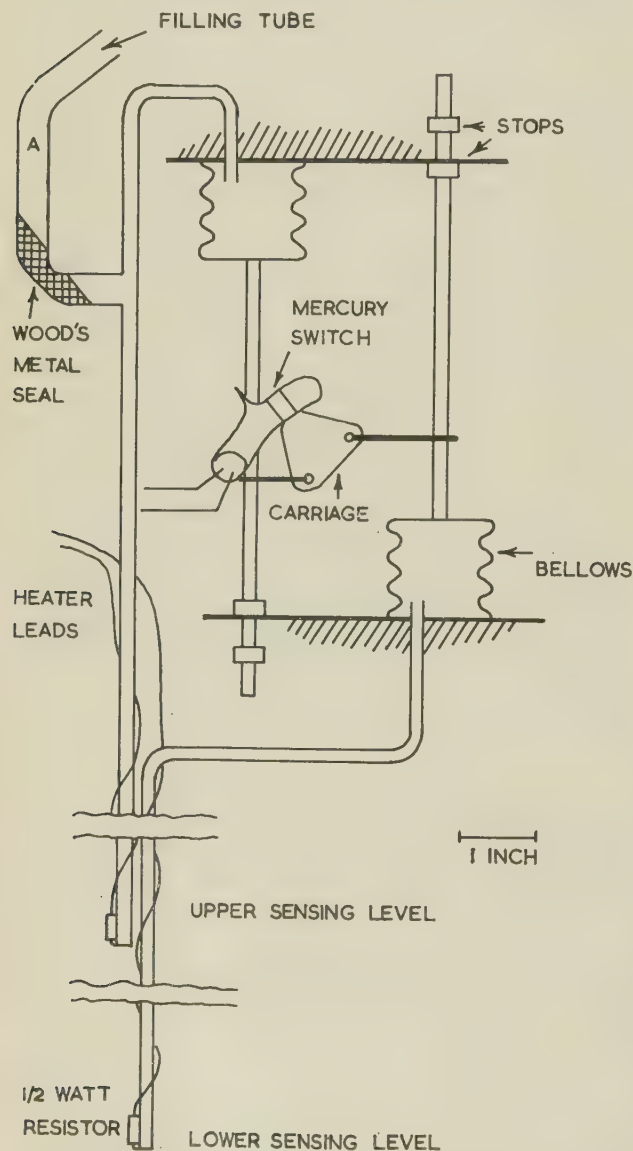


A level controller for liquid nitrogen

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MS. received 31st October 1960

Many forms of cryogenic liquid level indicator can be adapted to keep the liquid level automatically at a fixed point (Jones 1948, Box and Walker 1950, Quinell and Futch 1950, Hereward 1951, Zweig 1951, Lounsbury 1951, Davies and Kronberger 1952, Sherwood 1952, Goodwin 1955, Henshaw 1957). In the case of metal Dewars, where constant temperature conditions are maintained over a range of refrigerant depths, this is wasteful of liquid in frequent transfers. In principle most of the indicators can be adapted, by providing



Schematic diagram of nitrogen level control device. The switch is in the transfer (closed) position, and both bellows are expanded. Only one filling tube is shown.

two sensing elements, to refill the Dewar only when the liquid falls below a set minimum level (Fred and Rauh 1950, Wexler and Corak 1951). However, the control system needed to do this is generally complicated. The following simple instrument was designed to control the refilling of the liquid nitrogen cooled radiation shield of a liquid hydrogen target (Bellamy, Hogg and Miller 1960) which has been used in nuclear physics investigations where reliable operation for many weeks is necessary.

The controller is shown in the figure. Each of the two vapour pressure thermometer sensing elements consists of metal bellows connected to a low thermal conductivity tube whose closed end is the sensitive level. Each bellows is filled to about two atmospheres with the vapour of the liquid to be controlled. The filling tube, shaped as shown, is tinned internally and partially filled with Wood's metal. When the Wood's metal lies in the straight section (A in diagram) the tube is open and the system may be evacuated and filled; when it lies in the bend the system is sealed. The Wood's metal is easily transferred from one position to the other by heating and tilting the tube. Filling causes the bellows to expand against a stop, the movement being about 5 mm. A 68 ohm $\frac{1}{2}$ watt carbon resistor is cemented with 'Araldite' to the lower end of each tube, and power is supplied by a 6.3 volt transformer winding. When a tube is immersed in cold vapour, enough heat is supplied by the resistor to keep the temperature of the coldest part of the tube above that corresponding to a vapour pressure of two atmospheres. The gas in the tube cools considerably, but because of the much larger volume of the bellows, there is only a small decrease in pressure. When the end of the tube is immersed in liquid, heat dissipation is much greater and the temperature falls so that vapour liquefies in the tube until the pressure in the bellows reaches one atmosphere, and the bellows contract against a stop. The bellows are arranged side by side as shown and expand in opposite directions.

The signal to start the transfer of fresh refrigerant is given by both bellows being expanded; the signal to stop by both being contracted. This signal is converted into a more convenient form by the mercury switch shown. This is a argon-filled glass tube with a hill in the middle formed by a 15° bend in the tube. A tilt of 25° either way from the horizontal is needed before the bead of mercury runs over to connect or disconnect the two wires fused in at one end. The switch is attached to a carriage hinged on each bellows. The position of the hinges and the stops of the movement of the bellows are chosen so that the switch is horizontal with the lower bellows contracted and the upper expanded. Expansion of the lower bellows or contraction of the upper tilts it 45° either way, making and breaking the switch respectively. Return to the state with the liquid level between upper and lower sensing elements from either extreme position does not affect the state of the switch. The switch has been used to operate directly either 250 volt a.c. magnetic valves admitting nitrogen gas from cylinder to pressurize the refrigerant storage or a 25 watt heater immersed in the refrigerant storage. Each system draws about 100 ma current. Arcing in the switch is prevented by connecting a $0.02 \mu\text{F}$ condenser in series with a 68 ohm resistance across it. The instrument is not affected by small departures from the vertical in its installation and reliable operation over hundreds of cycles has been obtained without difficulty.

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Power oscillator for small synchronous motors

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Small synchronous clock or timer motors find wide application as pulling motors for crystal growing and zoning purposes, but have the disadvantage that changes in speed can be obtained only by changing the gear ratio. Tests on representative motors of various types indicate that most of them will operate satisfactorily over a frequency range of 30 to 600 c/s, but are self-starting only over a narrow range centred on mains frequency. This note gives details of a cheap and simple power oscillator of good

frequency stability suitable for driving this type of motor at variable speeds.

The circuit is shown in the Figure. It is not in any sense original, consisting simply of a Wien bridge oscillator and power amplifier, but its design incorporates a number of features which are essential for motor driving.

1. The full operating frequency range is covered in a single range.

2. Good frequency stability.

3. The amplifier has a rising frequency characteristic which, if combined with current feedback, maintains adequate motor torque at the higher frequencies.

V_{1a} – V_{1b} form a conventional Wien bridge oscillator with positive frequency-selective feedback from V_{1b} anode to V_{1a} grid via R_8 – VC_{1a} , VC_{1b} – R_4 . Negative feedback from V_{1b} cathode is adjustable by R_{10} . Amplitude stability of the output oscillation is maintained by a thermistor in parallel with V_{1b} anode load. It should be noted that VC_1 frame must be insulated from earth, and it is desirable to enclose the Wien bridge elements in a screened compartment.

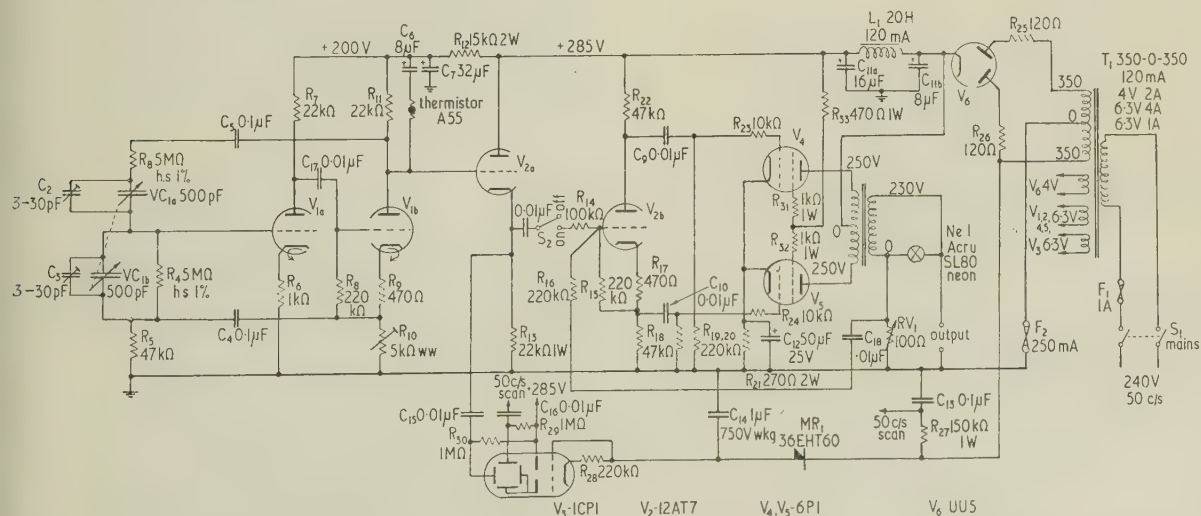
Output from V_{1b} feeds a simple push-pull power amplifier V_{2b} , V_4 , V_5 via a cathode follower V_{2a} . The input coupling time-constant is chosen to give a rising frequency response at the lower end of the frequency range. Current feedback from the load is applied to V_{2b} grid to enhance this effect. The output transformer is an ordinary 250–0–250 v, 380 mA, h.t. supply transformer used in reverse.

A small monitor cathode-ray tube V_3 has mains frequency fed to its X-plates and oscillator frequency fed to its Y-plates and provides convenient spot-frequency check points. The power supply need not be stabilized but h.t. to V_{1a} – V_{1b} must be well smoothed to avoid cross-modulation effects at frequencies near multiples of 50 c/s.

For the circuit given the frequency range is of the order of 40–600 c/s; frequency stability is about ± 1 part in 400 after 10 minutes warm up. Output voltage rises from 200 v at 40 c/s to about 400 v at 200 c/s; thereafter the output stage limits and the waveform becomes more square, so that the power input to the motor continues to increase without further rise in voltage.

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A simple plasma oscillator

by G. C. McCULLAGH,[†] Physics Department, Queen's University, Belfast

Communicated by Professor K. G. Emeleus. MS. received 26th October 1960

Abstract. A simple and easily constructed plasma oscillator is described, giving power of the order of microwatts, and tunable over rather wide ranges, e.g. 40–55 cm, by varying the anode voltage.

In some experiments in progress in this laboratory on the high-frequency properties of plasmas, it has been necessary to have available a source of high-frequency oscillations capable of considerable frequency variation in the decimetre wavelength range. Since high power was not of importance, it was decided to use a plasma oscillator for this purpose. The object of this note is to call attention to the usefulness of such a device, and to describe a simple, easily constructed tube.

Plasma oscillators are based on the principle that a beam of electrons from a hot cathode can both maintain a plasma, and set the plasma electrons into longitudinal vibration with about the Langmuir frequency

$$\{Ne^2/(\pi m)\}^{1/2} = 8980 N^{1/2} \text{ c/s,}$$

where N is the plasma electron concentration. The oscillations are picked up by the electrodes, and high-frequency energy withdrawn from them.

The design of tubes for this purpose was considered independently by Wehner (1950) and by Armstrong and Emeleus (1949). The tube ultimately developed by Wehner is a sealed-off, essentially planar system with a Gabor-type cathode. Whilst very satisfactory in operation, it has a somewhat complicated structure, and replacement of the cathode in event of failure is liable to be time-consuming. We have therefore used the simpler filamentary cathode form studied by Armstrong and Emeleus. This is rather more liable to exhibit discontinuities in operating characteristics than Wehner's form, but is very easy to build and maintain, and has been adequate for our purposes.

A tube of this type is shown in Fig. 1. It is a demountable

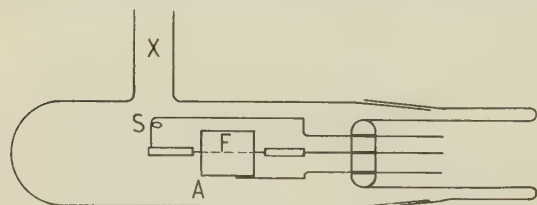


Fig. 1. Cylindrical plasma oscillator. A, anode; F, cathode; S, small coiled spring; X, lead to mercury reservoir, to control pressure, and to pumping train.

diode with a tungsten filament F, 0.2 mm in diameter and 1.5 cm long, on the axis of an open-ended cylindrical nickel anode A, 1.3 cm long and 1.0 cm in diameter. The filament is held taut by a small spring S, this being apparently one of the conditions for optimum operation (Armstrong and Emeleus 1949). The discharge is passed through mercury vapour at a pressure of the order of 1μ . The tube is earth shielded, and high-frequency power of the order of micro-

watts (Armstrong and Emeleus 1949) is withdrawn from or other of the electrode leads by a coaxial line.

The frequency of the plasma oscillations depends on the pressure p , filament current I , and anode voltage V . For most purposes it is convenient to keep p and I constant and to change V . Different parts of the tube current (i), characteristic have different oscillation ranges. Below saturation there is a tendency for low-frequency noise with components up to rather more than 1 Mc/s to be present. Near and above saturation several high-frequency oscillations may be generated, under some conditions, apparently simultaneously.

The behaviour of the tube under a typical set of running conditions is illustrated by Fig. 2. Tuning to different frequencies could be effected simply by changing the tube voltage V . Other frequency ranges can be obtained as described by Armstrong and Emeleus (1949).

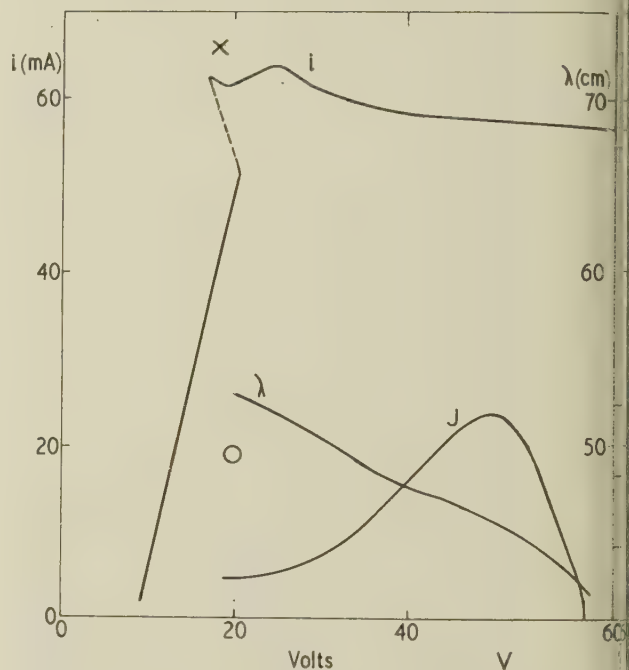


Fig. 2. Curves to show typical performance of diode. V , tube voltage; i , tube current; λ (cm), free-space electromagnetic wavelength equivalent to frequency of oscillations; J , intensity of oscillations in arbitrary units. The broken section of the (i , V) curve is a region of instability: two wavelengths were obtained over it, with λ values of approximately the values shown by X and O. The dimensions of the tube are not critical. The wavemeter was connected to the negative cathode lead.

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The use of this oscillator was suggested by Professor Emeleus.

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production of high-quality optical surfaces on calcite

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order to produce birefringent plates of calcite for the
yot filter described elsewhere (Steel, Smartt and Gio-
li, to be published), a technique of polishing calcite has
developed that differs somewhat from those usually
ibed. With this method it is possible to obtain con-
tly a surface flat to $\frac{1}{2}$ or, with care, $\frac{1}{10}$ of a fringe, free
surface defects or perceptible 'turned down' edge. It
been used successfully for surfaces at most orientations
e crystal optic axis, including cleavage planes, but fails
surfaces normal to the axis as the polishing tends then to
e out small tetrahedra from the surface. Such surfaces,
ver, are rarely required on calcite components; they can
polished to a lower surface quality using cloth polishers.

Calcite is initially examined for uniformity of bire-
fringence as described in the account of the filter. Suitable
s are cut from the crystal by hand using a tensioned
wire and carborundum powder in dilute detergent
ion. The surfaces are ground on a slightly convex
iron lap.

A flat polished surface is most easily obtained on calcite
using a hard pitch polishing lap, but scratching of the
ce is then more likely than when a soft pitch is used.
has led to the use of a hard lap with a very thin soft
ce. The risk of scratching is also reduced if the polishing
s on the lap are small (area 3 mm² or less) and widely
ed, if all lie accurately in a plane, and if the edge of the
al is chamfered and lightly polished. Similar laps have
been used with advantage to polish other soft materials,
ing flint glasses, and even hard glasses such as fused

A special lap is produced by preparing a hard pitch lap,
t 8 in. diameter, with suitable facets on the surface.
surface is then softened by pouring over it a suitable
nt: for wood-pitch, alcohol is used. The solvent is
ed off with water after a few seconds; too long a treat-
ruins the lap. The polisher is used on a slow-speed
ine (50–100 rev/min) with a 6 in. glass flat being
eked' by the machine across it; this smooths the surface
distributes the polishing powder. The calcite is simul-
ously polished by hand on the side of the lap, being
in a felt 'jacket' for thermal insulation. Black Fe₃O₄
(ssite) is used in small quantities as the polishing agent.
polishing is necessary to avoid surface distortion due
e non-uniform thermal expansion of calcite; the use of
y spaced facets on the polisher reduces the heating of
alcite surface.

ry thin plates are contacted optically to glass plates for
hing; this contact is obtained more readily if the surfaces
been previously cleaned with a mixture of alcohol and
r with a few drops of a detergent such as 'Teepol'.

urate control of thickness of birefringent plates is
rtant. To avoid repeated tests of the plate's thickness
ardation, a small hollow is polished in the centre of
urface, its depth being found by interference, and the
ce then polished down to just remove it; a flat polisher
not increase the depth of such a hollow. Also, most
s required local figuring of one surface to give uniform
ation across the plate. This local figuring is done by
using small pitch or cork polishers and Linde 'A'
er.

The surface is dried as soon as finished, as even water of
pH 7 has been found to etch a polished face of calcite.

Mercury switch for establishing the true electrical zero in precise thermocouple measurements

by J. MIDDLEHURST, M.Sc., A.Inst.P., Division of
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In the measurement of thermocouple e.m.f.'s, it is common
practice to make the connection from each thermocouple
wire to its corresponding copper lead by a small mercury pool
in the bottom of a glass tube. The tubes are inserted in an
ice pot or triple-point cell which is used to establish the
cold-junction temperature.

It has been found that with 0.5 mm rare-metal thermo-
couples, the error caused by thermal condition down the
leads can be kept below 0.01° C by using copper wires of
0.010 in. diameter and immersing them to a depth of 10 in.
in the cold-junction container.

For measurements of thermocouple e.m.f.'s to better than
1 μ v, account must be taken of the parasitic e.m.f.'s caused
by inhomogeneities in the copper leads in regions of tempera-
ture gradient. Correction for this is made by determining the
electrical e.m.f. in the circuit on the 'measurement' side of
the cold junction. This is usually done by withdrawing the
thermocouple wires from the glass tubes and substituting a
piece of thin copper wire to short-circuit the outgoing copper
leads. This procedure is not entirely satisfactory for the
copper wire may itself introduce a spurious e.m.f. Further,
the act of making the new connection is clumsy and is likely
to delay measurements while the thermocouple wires come
to equilibrium once more at the cold-junction temperature.

The simple switching mechanism described here removes
all these objections. It consists of a set of six glass tubes,
0.05 in. wall thickness, joined a short distance from the
bottom. Four of the tubes, 0.2 in. o.d., take the thermo-
couple and fine copper wires. The other two tubes, 0.4 in.
o.d., contain spring-loaded glass plungers M and Z. All

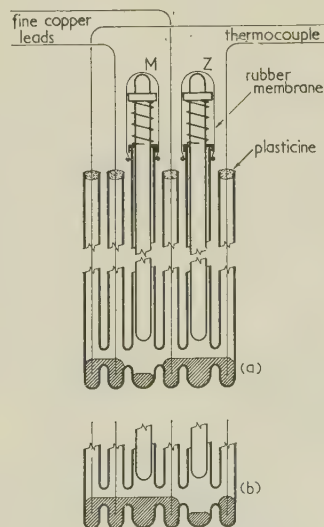


Fig. 1. Mercury switch.

except half of one of the larger wells at the bottom of the tubes are filled with clean mercury.

On pushing the plunger M to the bottom of its travel and releasing it, the mercury takes up a position as shown in Fig. 1(a) and the thermocouple is connected to the copper

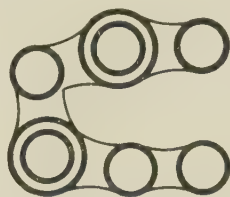


Fig. 2. Sectional plan showing actual arrangement of tubes.

wires (and thence to the measuring equipment). On pushing the plunger Z to the bottom of its travel and releasing it, as shown in Fig. 1(b), one side of the thermocouple is disconnected and the two copper wires are short circuited.

For compactness and rigidity the arrangement of the tubes, instead of being planar as shown in Fig. 1, is actually cylindrical, as shown in Fig. 2.

To prevent water condensing in the tubes with prolonged use, the tops of the small tubes are plugged with plasticine and each plunger is sealed with a thin rubber membrane. In common with other cold junctions of the mercury-pool type, the glassware is cleaned at weekly intervals by boiling in dilute nitric acid.

It can be seen that the switching action takes place as a result of the movement of mercury which is at the cold-junction temperature; furthermore, temperature gradients in all the wires remain constant during switching and no additional material in a temperature gradient (for example, copper wire) is introduced. Consequently, the switch described permits the establishment of the true electrical zero of the system. Tests have shown that any e.m.f.'s introduced by the switch are less than $0.01 \mu\text{V}$.

The author wishes to thank Mr. G. Nightingale for the construction of the glasswork.

Cold hearth zone refining

by R. M. WARE, The Plessey Co. Ltd., Caswell Research Laboratories, Towcester, Northants

MS. received 11th October 1960

This method is an extension of the cold hearth melting technique described by W. H. Shepherd (1960). The apparatus used is illustrated diagrammatically in Fig. 1 and the shape of the cold hearth itself can be seen from Fig. 2. The material to be refined rests in the depression in the upper surface of the cold hearth. The cold hearth

is constructed of copper and the surface of the depression is highly polished. The induction heating coil is mounted

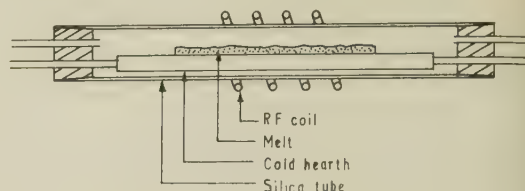


Fig. 1.

on a small trolley and connected to the high-frequency generator by flexible leads. By means of a motor and pulley system the trolley can be moved along the length of the silica tube.

So far this apparatus has been mainly employed on the purification of cobalt silicides and the results of one such

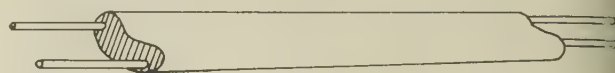


Fig. 2.

experiment are shown in the Table. The refining was carried out on a bar of cobalt disilicide 30 cm long and weighed approximately 200 g. The length of the molten zone was approximately 2.5 cm and the speed of zone movement was 25 cm/hour. The bar was turned over after each pass. Impurity contents were determined spectrographically.

One point of considerable interest is the extent to which pick-up of copper from the hearth occurs. It is evident from the spectrographic analysis that such pick-up, if it occurs at all, is very slight. The reasons for the lack of copper contamination are thought to be:

- (1) The high thermal conductivity of the copper ensures that the temperature of the upper surface of the hearth is comparatively low, probably not above 100°C .
- (2) A thin layer of the silicide in contact with the hearth remains solid.

Under these conditions the diffusion of copper into specimen should be small.

Cold hearth zone refining may be considered as an alternative to floating zone refining for the purification of highly reactive materials. It has the advantage that it is much simpler to carry out in practice but the disadvantage is that it does not seem possible to grow single crystals.

Thanks are due to the Plessey Company Limited for permission to publish this note.

SHEPHERD, W., 1960, *J. Sci. Instrum.*, **37**, 177.

Table. Purification of CoSi_2 by zone refining

Specimen	Ni	Fe	Mn	Al	Impurities					
					Ag	Ca	Cu	Ga	Mg	Na
Before refining	0.25%*	0.12%*	s.t.	tr.	s.t.	s.t.	s.t.	s.t.	s.t.	s.t.
Starting end after 8 passes	0.10%*	0.05%*	n.d.	s.t.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Finishing end after 8 passes	0.69%*	0.025%	tr.	tr.	n.d.	n.d.	tr.	n.d.	n.d.	n.d.
Starting end after 14 passes	tr.	s.t.	n.d.	n.d.	n.d.	n.d.	s.t.	n.d.	n.d.	n.d.
Finishing end after 14 passes	Small quantity†		tr.	tr.	n.d.	s.t.	tr.	tr.	n.d.	n.d.

n.d. = not detected.

tr. = trace, 10–50 parts per million.

s.t. = slight trace, 1–10 parts per million.

* Chemical analysis of Ni and Fe content.

† = chemical analysis not carried out.

Improvement to the floating zone method of growing single crystals

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MS. received 5th December 1960

During the development of an automatic machine for floating zone refining (Bardsley 1959, Keck and Golay 1953) and single crystal growth of silicon, we experienced a common difficulty of keeping the silicon rod straight for long operating periods.

Any initial displacement of the rod axis relative to the

electrical centre of the r.f. coil causes an asymmetrical molten zone. This results in the rod bending, cumulatively with successive passes of the molten zone so as to increase the displacement, until the rod eventually touches the envelope wall. The radial thermal symmetry of a straight rod is improved by rotating it relative to the coil.

Even so, any slight deviation from straightness of the rod results in a greater heat input to the part of the rod nearest the coil, which again leads to cumulative distortion.

Our solution to this problem was to rotate the ends of the silicon rod at the same rate (a few revolutions per minute), but in opposite directions, about the molten zone. This was completely effective, not only in maintaining the straightness of rods for an indefinite number of passes but also in correcting for any initial misalignment between the rod and the seed crystal (Fig. 1). Furthermore, rods of non-uniform diameter which were grossly bent, for the purposes of testing the system, even to the extent of touching the envelope wall, were still straightened automatically (Fig. 2).

In order to avoid difficulties when starting, with the whole silicon rod solid, the upper chuck was hung from its support by means of a ball joint. This arrangement has the following advantages: (i) the ball joint acts as a clutch, and slips until the rod is molten right through; (ii) it is also designed to allow some axial freedom so that the rod can expand on initial heating up, but before melting through (the lower chuck is free to slide axially on its support so as to allow for contraction of the solid silicon rod on cooling).

This technique of contra-rotation has also been demonstrated successfully in the floating zone refining of Indium Antimonide and could doubtless be applied more generally.

Acknowledgment is made to the Controller, H.M. Stationery Office, for permission to publish this paper.

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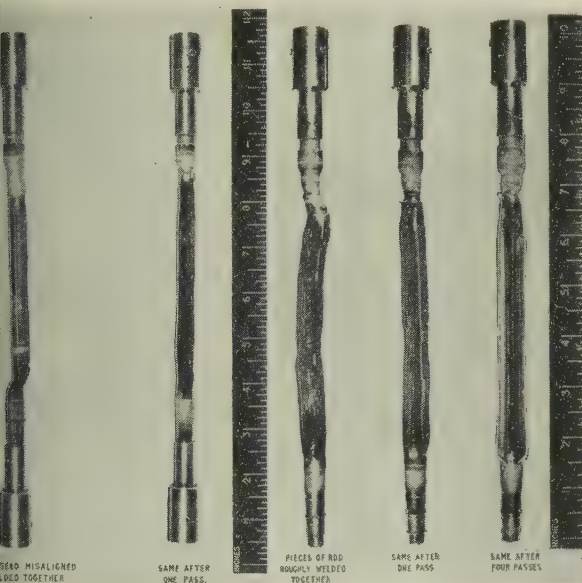


Fig. 1.

Fig. 2.

CORRESPONDENCE

Comments on the A.S.T.M. Powder Data File—6

Writers have now prepared a sixth booklet, bearing the title, which contains further additions to the lists previously published and described in the Institute's *Journals* (Hughes, Lewis and Wilson 1960). Copies of the present booklet have been distributed in the same way as were the previous ones. Those who have not received copies of the booklets in this way may obtain them (free of charge) on request from the Institute and Society or from us.

It is hoped that similar lists of comments will continue to be published at approximately annual intervals. Users of the File are urged to send to the writers any material that they feel should be included in future issues.

It would help considerably in the work of extending the File if those who are working on structures by single-crystal methods could send us the crystallographic data and sufficient of their material to permit the production of a powder pattern from it. Full acknowledgment of the source would, of course, appear on the published card.

Viriamu Jones Laboratory,
University College, Cardiff,
Great Britain.

J. W. HUGHES
ISABEL E. LEWIS
A. J. C. WILSON

3rd January 1961

HUGHES, J. W., LEWIS, I. E., and WILSON, A. J. C., 1960, *Brit. J. Appl. Phys.*, **11**, 306; *J. Sci. Instrum.*, **37**, 183.

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep her informed of their new or improved products. The Institute of Physics and The Physical Society assumes no responsibility for the statements given below: information for these has been taken from literature supplied.

Nuclear track measuring microscope. VEB Carl Zeiss JENA, Jena/Thuringia (DDR), Germany.

This microscope has been designed to facilitate scatter measurements of high energy nuclear particle tracks in photographic emulsions. For high energy particles, track deviations are of the order of 0.1μ or less and in a measuring apparatus departures from linear movements (so-called 'stage noise') must be kept as low as possible. In this microscope these deviations are claimed to be from 0.005 to 0.02μ depending on the cell length used. The noise of the objective movement is of the same order. Both stage and objective movements can be checked at any time by means of a built-in interferometric device. Precise measurements can be made of depth, angle and gap. A switch enables the observer to change from illumination of the object to illumination of the scales. Three scales, one for depth adjustment, one for scatter measurements and one for angular measurement can be read simultaneously and a built-in microphone enables the observer to record observations on a tape recorder. Thus the operator need never take his eyes away from the microscope during an entire series of measurements.

Continuous writing streak camera. Beckman and Whitley, Inc., San Carlos, California, U.S.A.

Producing an uninterrupted streak image 50 inches long on 35 mm film, the new Beckman and Whitley Model 339 sweeping-image camera is always in recording condition during operation. It can therefore be used for the documentation of randomly occurring events which are not suitable for synchronization with the instrumentation.

Writing rate for the new camera is 9 mm per microsecond at a maximum mirror speed of 2600 rps. Time resolution is 5×10^{-9} seconds or better, and minimum total writing time is 145 microseconds.

Some new features have been incorporated into this instrument. These include the use of a beryllium rotating mirror which is essentially distortion free at operating speeds; an all-mirror, axially aligned relay optical system which permits operation in the far ultraviolet region; a newly developed film-track configuration which gives a flat film plane and a transistorized automatic turbine-speed monitor which provides an overspeed safety cut-out.

Other features include the ability to operate in various positions, 100-foot daylight film loading and arrangements to permit operation as a synchronized streak camera where required.

Scintillation counter FT 165. Hilger & Watts Ltd., Camden Road, N.W.1.

The FT 165 Scintillation Counter is intended for use with x-rays in the range $0.3 \text{ \AA}$ to $3.5 \text{ \AA}$, and where resolving times

of about 2 microseconds are needed. The transducer consists of a crystal of thallium activated sodium iodide coupled to a sensitive photomultiplier, the E.M.I. type 9524 A. The housing in which the two components are mounted also contains the appropriate circuitry for the dynode chain. The crystal, 1 inch diameter by 1 mm thick, is set in an aluminium demountable cylindrical container with a window top and bottom. The window through which the radiation passes is made of beryllium, while that on the other side, coupling the crystal to the photomultiplier, is of spectacle crown glass. Between the crown glass window and the crystal is a thin film of silicone fluid, and magnesium oxide surrounds the top of the crystal to prevent absorption of the scintillation. The E.M.I. type 9524 A has a working voltage of about 1.3 kV and a load of approximately 0.3 mA down the dynode chain. It gives more than $70 \mu\text{A/lumen}$ at the photocathode. Typical applications include detection in x-ray diffraction and x-ray fluorescence analysis, also energy measurement of x-ray and gamma radiation.

Half inch condenser microphone. Bruel & Kjaer Laboratories Ltd., Tilney St., W.1.

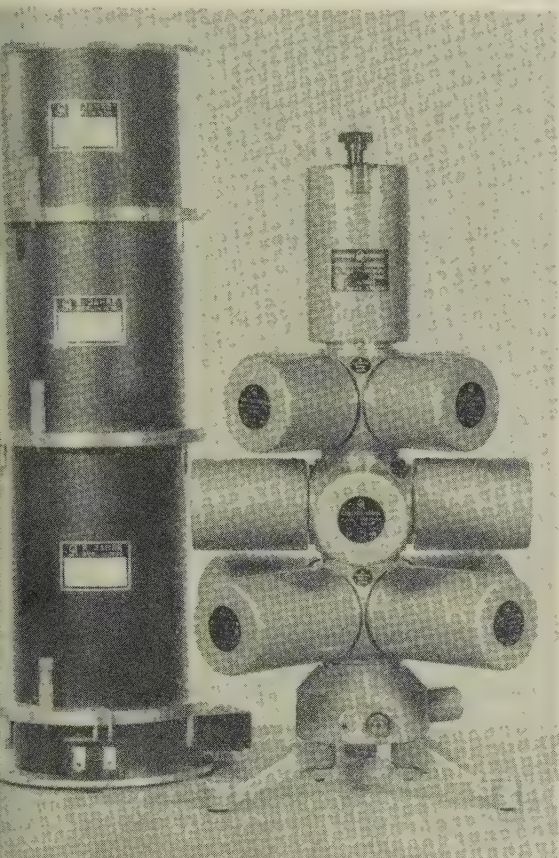
This new design of condenser microphone is produced in two types. The Type 4133 has a linear frequency range from 20 to 40 000 c/s within approximately $\pm 1 \text{ dB}$ for sound waves impinging perpendicular on the diaphragm and is intended for use in free-field measurements. The Type 4134 has a linear frequency response from 20 to 20 000 c/s (within $\pm 1 \text{ dB}$) and is meant for use in a diffuse sound field or under acoustic pressure conditions. Both microphones are capable of measuring sound pressure levels above 160 dB relative to $2 \times 10^{-4} \mu\text{b}$; also they are claimed to have excellent stability and temperature characteristics which make accurate measurement well above 150°C possible. Two new cathode followers Type 2614 and 2615 have been developed, which match the microphones. They have been designed to withstand shock and vibration with a minimum of microphone and to remain unaffected by adverse conditions of moisture and heat.

Membrane filter. Gelman Instrument Co., Michigan, U.S.A.

The membrane filter is a thin plastic material with a spongy like network of holes in it. The hole size in the filter is extremely uniform. Grades are available with holes as large as 10 micron or as small as 0.05 micron . The membrane is used to remove particles from both liquids and gases. The closely controlled pore size of the filter causes these particles to be collected primarily on the filter surface. This property is extremely valuable when dealing with radio-isotopes since corrections for self-absorption during subsequent detection are virtually eliminated. The inertness of the membrane additionally insures no contamination of the solution being filtered or adsorption on the filter. The membrane is used to remove radioactive particles from air and gases. This is done either for the purpose of purification or for collection of samples for subsequent analysis. Samples of radioactive aerosols collected from air may be counted directly or after combustion. A radioautograph may be made by placing nuclear emulsion film on top of the membrane filter.

Capacitance Standards. Aveley Electric Ltd., Aveley Road, South Ockendon, Essex.

System of capacitance standards, manufactured by Richard of Berlin, enables any capacitance from 10 pF to 10 μ F made up without the use of switches. The system comprises a range of screened capacitors which plug into connectors arranged in a vertical stack to form an 'Xmas Tree' assembly, any unused ports on the blocks being covered by screening caps. This form of construction occupies little



space, is convenient in use, and is claimed to ensure stability of the standards with normal care in handling. The range of fixed capacitors is such as to provide 10 pF increments which can be bridged by variable capacitors of 16 pF to 10 pF. Air dielectric is used in the sizes up to 400 pF and has loss factors below 1 in 10^5 . The coaxial construction system ensures complete screening and high natural resonant frequency, the series inductance per unit being less than 0.06 μ H. Each unit is adjusted to $\pm 0.1\%$, ± 0.1 pF is issued with a calibration certificate. Temperature coefficient is 20 parts per million per $^{\circ}$ C for units up to 10 pF and 30 parts for larger units. Long term stability is guaranteed to be better than 0.05% per annum. In practice, drift of the order of 0.01% per annum may be expected with normal usage.

X-ray system model 5660. Zenith Radio Corporation, Chicago, U.S.A.

The system employs an oxide-coated hot cathode tube which is pulsed with a 1 μ s square wave adjustable in ampli-

tude from zero to 150 kv and in repetition frequency from 1 to 30 pulses per second. It is claimed that the tube has a life exceeding one million shots while maintaining excellent reproducibility of x-ray output characteristics. When operated at maximum voltage with a beam current of 130 amps the resulting rays have an effective spot size of 1 mm $\times$ 2 mm, which is maintained throughout the life of the tube, and an intensity of 10^7 röntgens per second.

A Rauland image intensifier tube is used to produce an image suitable for direct viewing, closed-circuit television viewing, or for cine recording. For the latter purpose the light intensity is sufficient to permit the use of ultra fine grain film. A feature of the equipment is that a single pulse has energy sufficient to permit a radiograph to be taken directly on conventional film, adequate intensity having been obtained through 1.5 in. of aluminium at a distance of 6 ft from the target.

The system may be triggered manually, or continuously by an internal pulse generator, or by an external source, while a reference pulse is available for synchronizing auxiliary equipment. The x-ray generating console is 26 in. $\times$ 22 in. $\times$ 47 in. and consumes 2500 watts, while the intensifier console is 21 in. $\times$ 22 in. $\times$ 47 in. and consumes 400 watts.

Potential applications for the system which have been cited include the studies of physiological processes, of components subject to vibration and shock in their normal operating environment, and of molecular and crystalline structure under dynamic conditions.

Solid state digital multimeter M7. Packard Bell Computer Corp., Los Angeles, U.S.A.

This is a new analogue to digital converter for measuring a.c. and d.c. voltages plus resistance, frequency and period. It is claimed that measurements from 1 c/s to 100 kc/s can be made with an accuracy to $0.01\% \pm 1$ count. A measurement is completed in 0.1 second. Periods from 0.001 to 0.1 second can be measured with an accuracy to 0.01%. Voltage and resistance ranges extend to 1000 volts a.c. or d.c. and 1 megohm. The design fulfils U.S.A. military equipment requirements.

Uguine-Evraud continuous recording balance. Société D.A.M., Lyon, France.

The movable part of the equipment consists of an ordinary analytic balance beam, polished aluminium alloy, with agate knife-edges. It is lodged with its suspensions inside a vacuum case whose interior polished surfaces allow rapid removal of gases. Beam movements are detected by means of a pencil of light and a photoelectric cell. The weight variations of the sample are automatically compensated for by the magnetic force developed by a coil on a small permanent magnet. The intensity of the electric current constitutes a measure of weight when the beam deflection is at or very near a null balance. The control amplifier serves two purposes:

- (1) It produces the balancing current through the coil by detecting and amplifying the variation in photocell current.
- (2) It delivers a damping current into the coil which is proportional to the speed of the movable beam.

The potential difference derived from the coil current can be applied to a millivoltmeter or a recording potentiometer.

New books

Tools of biological research, 2nd Series. Edited by H. J. B. ATKINS. (Oxford: Blackwell, 1960.) Pp. xii + 175. Price 37s. 6d.

The tools in this collection are a mixed bag and the same goes for the essays describing them. The book is designed for the instruction of surgeons engaged in research and includes much that they will find valuable, along with a few contributions of smaller merit. The expectations induced by a penetrating introductory comment (from Lord Cohen of Birkenhead) on the role of the scientist in medical research are fulfilled in the first chapter when S. J. Wyard describes the technique and biological applications of electron spin resonance spectroscopy. Dealing mainly with the detection and study of free radicals in biological materials, he gives an admirably clear account of the method, its applications and its shortcomings.

Contributors writing on topics with a less distinct scientific basis have a harder task and some of them do it very well—notably Ivor Smith on paper chromatography, Paley Johnson on the ultracentrifuge and G. J. Cunningham on microradiography. D. C. Phillips gives a knowledgeable account of structure determination by x-ray crystallography, but his opening pages contain a good deal of mathematical discussion which will certainly repel all but the bravest surgeons.

In general the choice of subjects and the manner of treatment are suitable for the intended readership. Physicists associated with biological research will find the book useful for reference.

J. M. A. LENIHAN

Wave generation and shaping. By L. STRAUSS. (New York, Toronto, London: McGraw-Hill, 1960.) Pp. xiv + 520. Price 97s.

The great advances in electronic circuit design during the war put the subject of wave (or waveform) generation and shaping on a firm footing. The extensive work on radar showed that circuits could be accurately designed. Many of the best circuits are indeed designed to work in spite of the imperfections in the valves or transistors. The work on this subject during the war was recorded in the classic volume *Waveforms* in the Radiation Laboratory series. There have been many advances in the years since the war, the most spectacular and important of which has been the invention of the transistor. The present work is to be welcomed as an up-to-date textbook on electronic circuit techniques including both the use of the thermionic valve and the transistor.

The book is divided into five parts, the first of which is concerned with fundamentals. This begins with a discussion of linear shaping techniques and continues with a thorough treatment of the properties and applications the diode, triode, pentode and transistor. The equivalent circuits are novel because they represent the operation of these devices for both linear and non-linear operation. In this way the author succeeds in giving a unified approach to the design of circuits using transistors or thermionic valves.

The second part on 'Timing' is concerned with generation of voltage and current waveforms which are linear functions of time. This begins with the generation of exponential

sweeps and describes the standard miller and bootstrap circuits for obtaining linear sweeps.

The third part is devoted to switching circuits and includes a unified treatment of thermionic valve and transistor multivibrators. The connection of these circuit in chains to form a counter is unfortunately only briefly mentioned. The description of negative resistance switching devices is useful and embraces the recently introduced p-n-p-n junction transistor and tunnel diode. This part ends with a useful discussion of blocking oscillators.

There is a short part on circuits, including shift registers which use magnetic cores as storage elements. The final part deals with oscillators and includes RC, LC and negative resistance devices.

The book has just the right balance between theory and practice. Each chapter has a moderate number of references and ends with a set of useful problems. It can be recommended to students and all who wish to learn about and use waveform generation circuits.

R. L. GRIMSDALE

Fundamentals of digital instrumentation. By D. S. EVANS. (London: Hilger and Watts, 1960.) Pp. 39. Price 7s. 6d.

This small monograph is concerned with methods of converting from analogue to digital presentation. It is intended to fill the gap between scattered magazine articles and the few available technical books on the subject.

A section on coding is followed by a description of the method of 'choosing' to avoid ambiguities in read-out systems. Some details follow about relay decoders, and the application of the output of these decoders to display and print-out systems is indicated. Brief mention is made of sampling, storing and time sharing. A short section on resolution of digitizers concludes the book. Discussion throughout is limited to shaft-driven digitizers.

Fifteen pages of the book are filled with well presented diagrams and photographs, and the all too brief text, which contains a few minor printing errors, has been spread over a generous twenty-four pages. The value of this monograph could have been greatly increased if it had not been kept so drastically brief and a broader approach had been taken. The absence of any bibliography is most regrettable in a book intended as an introduction to the subject.

C. S. C. TARBET

Transistor circuit analysis and design. By F. C. FITCH. (Princeton, New Jersey, Toronto, New York, London: Van Nostrand, 1960.) Pp. xi + 356. Price 56s.

This book can be considered as three nearly equal parts. The first discusses the behaviour of the transistor as an electronic circuit element at low frequencies, and includes very careful consideration of temperature effects and tolerances. The next part deals with linear, low-frequency amplifiers, including negative feedback and a brief discussion of direct-current amplifiers. The third part deals with other characteristics of transistors, such as noise and high-frequency performance, and application of transistors as oscillator mixers, detectors, etc., while the final chapter is devoted to pulse circuits. This last chapter is unfortunately not up to

standard of the rest of the book. There are some useful tables, including tabulated characteristics of some commercially available American transistors. The first two-thirds of the book are excellent. The outlook is roughly practical, while at the same time the fundamentals of transistors are kept well in view. The treatment is not excessively mathematical and the reader is aided by worked examples. In addition there are problems at the end of each chapter. The last third of the book deals briefly with subjects which are more difficult, and for this reason is less satisfying, though it is a useful introduction to further reading.

In general, the book forms an excellent introduction to transistor circuit design, and the reader who has mastered it will avoid many of the pitfalls into which many quite experienced transistor circuit designers are apt to fall.

E. H. COOKE-YARBOROUGH

Laboratory and workshop notes 1956-1958. Compiled and edited by RUTH LANG for The Institute of Physics. (London: Edward Arnold Ltd., 1960.) Pp. xii + 218. Price 40s.

This fifth volume of *Laboratory and Workshop Notes*, reprinted from the *Journal of Scientific Instruments*, is a selection from those published during the years 1956-1958. They are divided into six main sections: Mechanical design, workshop techniques and materials; Laboratory techniques and devices; Optical and thermal techniques and devices; Techniques and devices for use with liquids and gases; Vacuum devices and techniques; Electrical and electronic devices and techniques. This periodic reprinting from *Laboratory and Workshop Notes* in this classified form is of great assistance to readers in back reference to the articles.

Notes and comments

C. V. Drysdale

Many readers will be sad to learn of the death of Dr. C. V. Drysdale recently at the age of 86. Dr. Drysdale was elected Fellow of The Physical Society in 1898 and was a Founder member of The Institute of Physics. He was a member of the Royal Advisory Committee of the *Journal of Scientific Instruments* in 1923 and was appointed its Editor on a part-time basis in 1925, a post which he held for three years until his ill health forced him to resign. He then accepted an appointment as an Honorary Adviser and served in this capacity until 1948. Those who had the privilege of working with him will always remember the ready help he would give those seeking his advice and his very profound knowledge and interest in scientific instruments and apparatus. A full obituary of Dr. Drysdale will be published in the *Proceedings of the Physical Society*.

Well Colour Centenary

The Colour Group, in collaboration with The Institute of Physics and The Physical Society and the Inter-Society Colour Council of America, is holding a Conference on Tuesday, Wednesday and Thursday, 16th, 17th and 18th May 1961 at the Imperial College of Science and Technology, London, W7, with a centenary discourse at the Royal Institution on 17th May.

This Conference is being arranged to mark the centenary of the famous demonstration of trichromatic colour reproduction given at the Royal Institution in London by James Clerk Maxwell on 17th May 1861.

The subjects for discussion on the three days will be Trichromatic Principles, Colour Reproduction and Colour Appearance. Each session will be opened by a short review

of the current position of the subject concerned, followed by papers by one or two well-known workers in the field; time will then be allowed for contributions by other conference members and for discussion.

Abstracts of the papers to be presented at the Conference will be published in the March/April issue of the *Journal of Photographic Science*.

Further details of the Conference are obtainable from The Institute of Physics and The Physical Society, 1 Lowther Gardens, Prince Consort Road, London, S.W.7.

Mesucora 1961

Mesucora, the International Exhibition devoted to Measurement, Control, Regulation and Automation, will be held at the Exhibition Hall of the Centre National des Industries et des Techniques, Paris, from 9th-17th May 1961. It will cover an exhibition area of 35000 square metres and bring together constructors from 13 European countries and the United States of America.

At the same time as the Exhibition, an International Congress will be held in Paris, the theme of which will be 'Recent progress in the fields of Measurement, Control, Regulation and Automation, resulting from the co-operation of the various techniques—electric, electronic, mechanical and nuclear.'

For further information apply to Mesucora, Service de Propagande, 40, rue du Colisée, Paris (8e).

Engineering, Marine, Welding and Nuclear Energy Exhibition

The Engineering, Marine, Welding and Nuclear Energy Exhibition will be held at Olympia, London, from 20th April-

4th May 1961. This biennial exhibition attracts close attention from buying authorities and technical personnel in every part of the world. The May issue of *Nuclear Engineering* will be a special issue containing a technical appraisal of equipment designed and manufactured for use in nuclear installations which will be exhibited at this Exhibition.

Commonwealth Technical Training Week

The Commonwealth Technical Training Week will be observed in many parts of the Commonwealth from 29th May–4th June 1961. Almost every local education authority in the United Kingdom will be participating; civic functions, careers conventions, open days at technical colleges, factories and training centres, youth service displays and sports, talks, film shows, etc., are being organized. Special services will be held at St. Paul's Cathedral, London, and St. Giles' Cathedral, Edinburgh, as well as at many churches throughout the country; the Roman Catholic and Jewish authorities are also supporting the Week.

The International Apprentices Competition will be held during July in Duisburg, Western Germany, and tests to select the British team will be conducted in April.

Laboratory Apparatus and Materials Exhibition

The second national Laboratory Apparatus and Materials Exhibition, sponsored by *Laboratory Practice*, will be held at the Royal Horticultural Society's New Hall from 19th–22nd June 1961.

Both British and overseas equipment will be shown.

Drawing Office Equipment and Materials Exhibition

The first national Drawing Office Equipment and Materials Exhibition to be held in the United Kingdom will be held at the Royal Horticultural Society's New Hall from 5th–8th June 1961. The exhibition is being held to give facilities to manufacturers of drawing office equipment and materials to show their specialized equipment and latest developments in this industry; both British and overseas equipment will be on show.

European Convention of Chemical Engineering 1961

The European Convention of Chemical Engineering will be held in Frankfurt am Main from the 9th to 17th June 1961. The programme will include the reading of 150 papers from 15 different countries and about 1300 exhibiting members of the Achema Congress from 15 countries will present the latest results of their development work in the field of chemical technology, chemical engineering and process engineering for discussion at the actual exhibits. A brochure is issued in English, French and German and may be obtained free of charge from the DECHEMA Deutsche

Gesellschaft für chemisches Apparatewesen, Frankfurt (Main) 7, Rheingau-Allee 25 (Postfach No. 7746).

International Instrument Show

The Sixth International Instrument Show will be held from 19th–24th June 1961. This Show is sponsored by B. and Laboratories Ltd. and specialists from many countries will attend to make the latest developments in precision electronic instruments available for inspection.

F.B.I. Register of British Manufacturers—1961. (London: Kelly's Directories Ltd. and Iliffe and Sons Ltd., for the Federation of British Industries, 1960.) Pp. 11. Price 50s.

The F.B.I. Register contains lists of the products and services of nearly 8000 member firms under more than 5000 alphabetical headings; other sections give addresses of companies and firms, information about trade associations, proprietary names, trade marks, etc., and French, German and Spanish glossaries give translations of every product term used in the main buyer's guide.

British Journal of Applied Physics

Contents of the April issue

CONFERENCE REPORT AND ASSOCIATED PAPERS

The Joint Conference of the Non-Destructive Testing Group and the Société Française de Métallurgie. By K. W. Andrews.
The structure of non-destructive testing. By K. W. Andrews.
The investigation of surface deformation. By L. Grunberg, D. Scott, and K. Wright.
Recent advances in magnetic analysis. By K. Hoselitz.
Frequency dependence of induced currents (abstract). By P. Graneau.

PAPERS

Rubber models of yarns and cords; the 'doubling' of single rods. By N. Williams and L. R. G. Treloar.
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Significance of the properties of materials in the packing of real spherical particles. By J. C. Macrae and W. A. Gray.
Porosity and surface area of a granular bed from measurements of the flow of air through the bed and measurements of the granular shape factors. By W. A. Jones and D. Mills.
Measurement of thickness of thin transparent films using fluorescence. By B. Bunt.
Conformal transformations by analogue computer. By E. J. Joss and D. S. R. Method for the consistent transformation of physical equations into a dimensionally parametric form. By J. C. Amson.
The determination of stress concentrations with an electrolytic tank model. By T. W. G. Calvert.
The coupling factor of piezoelectric ceramic disks. By D. S. Campbell and A. M. MacSwan.
The copper staining of p-n-p alloyed junction transistor sections. By S. Ratchford and J. E. Hughes.

CORRESPONDENCE

Comments on the A.S.T.M. Powder Data File—6. From J. W. Hughes, Isabelle Lewis, and A. J. C. Wilson.

NOTES AND NEWS

Notes and comments

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The Annual Exhibition of The Institute of Physics and The Physical Society—London, 1961

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Professor A. M. TAYLOR, M.A., Ph.D., F.Inst.P., Physical Laboratory, University of Southampton

THE 45th Exhibition of Scientific Instruments and Apparatus, 16th to 20th January, was the first to be held since the amalgamation of The Institute of Physics and The Physical Society. This year it seemed that more than ever had been successfully crammed into the Halls of the Royal Horticultural Society to which, as in the last few years, Exhibitors are indebted for accommodation. The impression given the visitor was as usual, one of careful organization, prodigious labour by all concerned, and of enthusiastic ownership by the exhibitors and demonstrators.

Of late years the criticism has been heard with increasing insistence, that the Annual Exhibition has become little more than a trades fair. Certainly at first glance, the array of glossy electronic boxes was overpowering. But after the first shock it became clear that exhibitors had attempted to limit their showings to apparatus that was genuinely new in some respect or other, and which for the most part was of interest to the practising research physicist and not only to those engaged in making routine measurements in industrial laboratories. There was, naturally, the now usual emphasis on instrumentation for nuclear work, on counters, kick-sorters and the like, but if such an array of diverse pieces of equipment could be said to have a dominant theme, it was the theme of solid state physics; even in technical details, the ubiquitous transistor threatens to oust the thermionic valve. The theme is seen equally in the more academic pieces of scientific inventions and devices in their homely laboratory appearance, as it is in the industrial equipment in its glossy boxes, often with digitalized display. Many research laboratories are intensifying their efforts to concentrate their forces as to advance, in breadth as well as depth, in the rewarding field of solid state physics; their progress is reflected in this exhibition. From the numerous examples two may be mentioned at the outset. The first is that remarkable demonstration of wave mechanical effects, the tunnel diode, which has been enthusiastically hailed as providing a fast switching device and as having high-frequency applications. However the tunnel diode appears to be unreliable, and present doubts are entertained on its ultimate value. The second, which is increasing its promise, is the work on magnetic domains; this, by giving us in thin films deposited in magnetic field, materials with suitable rectangular hysteresis loops, provides bistable components useful for storing information in binary form. These are two pioneering efforts that must have recurred to the minds of many visitors as with weary feet, and spirits drugged by continued stimulation, they departed from the exhibition in ruminant mood to rest and meditate. Although many will have had their imagination caught by other exhibits, all will have been most impressed by those in their own fields of interest, the reviewer among them; a review of such an exhibition must of necessity be tinted by the writer's own spectacles; coloration needs no apology; blind spots he regrets; distortion he hopes is absent. Some of the optical developments were elegant. Notable is a research cathetometer by R. & J. Beck Ltd. with

controls that are a delight to use, and a split image of the level bubble that has to be fused, rangefinder fashion, sensitive to half a second of arc. The same firm that produced this has made an optical bench of quality of design and construction that should satisfy even its fastidious recipient, Professor W. D. Wright of Imperial College, but which must cause many to shatter the tenth Commandment with violence; for these not even the thought of its probably astronomical cost can turn the grapes sour. Phase contrast equipment is no longer new, but a microscope designed by C. Baker Ltd. to give phase contrast, dark ground illumination or conventional transillumination, all at the turn of a lever, was shown under the name of *Trilux*; it should be a joy to many workers in biological fields.

For the man interested in topography of surfaces, there was shown a beautifully simple interferometer by W. Watson and Sons, made as one unit with a microscope objective. It is no more than a Lilliputian Michelson's interferometer, with the 'fixed' mirror the surface under examination, and it provides the observer with a conventional view of the surface by reflected light on which are superimposed fringes of equal depth from which the surface topography may be inferred as from a contour map. Moreover, by adjustment of the 'movable mirror' by means of the knurled head of the micrometer screw, the fringes can be moved laterally across the field of view, and quantitative observations made on the depth of surface features. The method is well known, but the equipment, standard and relatively inexpensive, is new and it must prove acceptable to many. It should be immediately adaptable to measurements of transparent specimens mounted on a reflecting surface.

For the equipment of teaching laboratories there was the usual array of microscopes of individually improved design, by almost every maker, for biologists, petrographers and others to take their choice, a choice which it must be admitted is not made any easier by the almost uniformly good design of all the exhibits. For the lecture bench there is a development which deserves to be tried as widely as possible: Taylor, Taylor and Hobson show a zoom lens of modest size, controlled manually, or by remote control, which is now available at a cost which will be within the means of many departments engaged in advanced teaching; if closed circuit television is already part of their lecture theatre equipment, the newly available lens will make their existing camera so versatile that the closed circuit television equipment may become an hundredfold more useful. This is something that should appeal to harassed professors whose courses are swollen by the population bulge, but who value practical demonstrations as an essential part of lecturing technique.

Hilger and Watts now produce hollow cathode lamps of great value, for they provide spectra with fine reference lines. Associated Electrical Industries (Lamp and Lighting Co.) showed new linear sodium lamps with luminous efficiency greater than 100 lumens per watt; these may be flashed. Their xenon arc is particularly valuable as a source of white

light of high intrinsic brightness, the luminosity being greater than 70 000 stilb.

Unicam enter the field of small infra-red recording spectrometers with an instrument of new design and moderate price. The Unicam flat-bed recorder may be used with it and provides a twenty-fold expansion of the scale.

A scanning Fabry-Perot interferometer is used by the Atomic Energy Research Establishment at Capenhurst for measurement of the relative intensity of components of hyperfine structure of spectral lines, yielding information concerning the relative abundance of isotopes. The well-known quantitative advantages of scanning are obtained, although in this instrument the scanning is produced by pulsating gas pressure in the space between the plates, and not by mechanical vibration of one of the plates.

One of the most interesting optical exhibits was the photoelectric spectropolarimeter designed by Gillham and King of the National Physical Laboratory and will shortly be manufactured. This uses the now familiar technique of a Faraday magneto-optical cell modulated with a.c. to provide the equivalent of the half-shadow device of a visual polarimeter, followed by electronic circuits to detect the null setting. The null setting is achieved when, in the output from the photomultiplier on which the light falls, the component of frequency equal to that of the a.c. modulation is reduced to zero amplitude. Measurements are made by maintaining the instrument in zero adjustment by controlling the d.c. current in a compensating Faraday cell; the rotation to be measured is then equal and opposite to the magneto-rotation produced in this cell; the current required is a measure of the rotation, and may be used to operate a pen recorder. The d.c. current is controlled by feedback from the detector following the photomultiplier.

The novelty consists in the double monochromator which is an integral part of the polarimeter. The two prisms are of crystalline quartz, both cut so that the optic axis is perpendicular to the ray traversing the prisms at minimum deviation. Natural light entering the first slit is both doubly refracted and dispersed by the first prism, so that light falling on the intermediate slit is of two widely different wavelengths, polarized mutually at right angles. At this point are placed the specimen, the compensating Faraday cell, and the modulating cell. Light passing through the second prism is again dispersed, so that what emerges from the exit slit is monochromatic and its intensity depends on the relative orientation of the optic axes of the two prisms. The positions of the three slits are such that the roles of polarizer and analyser, effectively crossed, are played by the prisms.

An ingenious development of C. V. Boys' radiomicrometer was shown by the Distillers Company. In this the thermocouple loop, hung in a magnetic field, has blackened gold leaf collector disks on both junctions, any difference in energy falling on the two giving rise to a thermoelectric current tending to deflect the loop. The deflection is detected by a mirror and photocell, and an amplifier provides a current which, passing through a feedback coil, maintains the loop in balance. This current is a measure of the differential energy flux and 10^{-9} watt is believed to be the ultimate sensitivity of the device. It should be of wide application in photometry.

The Kerr magneto-optical effect, discovered in 1877, but only now being put to good use, was demonstrated by International Computers and Tabulators and by the General Electric Company. Magnetic domains in the magnetic films become visible under polarized light. The demonstrations showed how the coherent rotation process can be exploited so

that the magnetic films can be used to store information. The matrix demonstrated can be switched in less than a microsecond, and it is expected that the ultimate switching time will be less than 10^{-9} second. The importance of such a fast device is obvious and the technique of production of suitable matrices seemed well advanced.

There was a very great number of cathode-ray tubes shown suitable for a variety of uses. One interesting development shown by Electronic Tubes Ltd. was of a tube coated with phosphor that glows blue on first stimulation, but afterwards shows a long decay green afterglow that, except in colour, comparable with that of the normal two-layer phosphor. However this is not the end; energy is stored in the phosphor and it may be released by irradiation with infra-red. The flux of the glow thus released may be controlled by the flux of infra-red radiation; it may even be released in steps, and not in one burst, by controlling the intensity and duration of the infra-red stimulus, which may be applied in successive doses.

A useful application of the cathode-ray screen as an illuminant has been made by Rank Cintel to the control of the density and contrast in photographic enlargements. The negative is illuminated by a flying spot on a cathode-ray screen, and the instantaneous brightness of the spot is controlled by feedback from a photocell recording the amount of light transmitted by the negative. This has the effect of altering the contrast between highlight and shadow, the available range of expansion or compression of contrast being from 0.7 to 2.15, adjustable in steps of 0.3. This however does not affect the reproduction of fine detail, but only the larger areas, so that overall contrast can be reduced (or flattened) while full contrast is maintained in the fine detail of both highlights and shadows alike.

English Electric Valve Company and 20th Century Electronics showed image intensifiers, the latter produced in collaboration with Professor J. D. McGee of Imperial College having an overall gain of 100 000. The former has a gain of 80 000 produced by five thin dynodes semi-transparent to electrons. The system is versatile in that there can be magnification or reduction in the final image size. These image intensifiers have already proved their value in work with faint sources of light, especially with the Čerenkov radiation from fast-moving electrons.

Nuclear Enterprises (G.B.) showed a complete range of scintillation phosphors, crystals and chemicals, including a new plastic phosphor with valuable pulse shape discrimination properties, and Nash and Thompson showed a glass scintillator GS1 developed by the British Scientific Instruments Research Association. This is a lithium alkaline earth silicate glass activated by cerium. Its sensitivity is but a fraction of that of a sodium iodide crystal but, being a silicate glass, it is chemically inert and can even be used in contact with strong nitric acid solutions, and will be especially useful in α -particle analysis.

Morgan Crucible Company manufacture high temperature thermocouples and as these incorporate non-metallic materials, e.g. graphite-silicon carbide or graphite-refractory metals, they may be used in strongly reducing surroundings such as when in contact with graphite or in carbonaceous atmospheres. Outputs are high, the graphite-silicon carbide couple yielding $200 \mu\text{V deg}^{-1}$.

Servo-mechanisms are of ubiquitous application but two only will be mentioned. One of fundamental importance shown by the National Physical Laboratory was an adaptive control system in which the information fed to the system was insufficient, but by a process of iteration the system adjusted

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own parameters to obtain the optimum conditions. More can be heard of this, which is of wide application to the control of industrial production. The other example at the exhibition which struck the reviewer as neat, was shown by British Iron and Steel Research Association and involved the servo-control of a correlator. This ingenious combination provided the solution to the problem of how to control the thickness of strip from a rolling mill. If the speed of the strip through the mill is known the solution may be inferred; the measurement of the speed that presents the problem. The problem is solved by reflecting light from the rough surface of the strip at two points in its path on to two photocells; the output from the photocells is fed, via two recording heads, to magnetic tape. Two reading heads feed the signals from the magnetic tape to a correlation circuit. The output is a maximum when the time delay between the two signals is exactly equal to the time of passage of the strip between the two points of observation. The output, suitably processed by servo-mechanism circuits, controls the separation between the two heads reading the magnetic tape. The time of passage between the points of observation is then known from this optimum setting of the reading heads for maximum correlation.

Magnetic tape has many uses. Northern Polytechnic has experimented successfully with 40 channel recording on $\frac{1}{4}$ in. magnetic tape. The recording is produced by the magnetic field surrounding fine wire, to which connections are made every few thousandths of an inch. Similar heads may be used for playback, but usually the tapes are analysed with magnetic powder. A matrix head was shown which records figures or letters directly on the tape; the visitor was invited to compose his own messages or, if invention ran dry, to write his own name, which duly appeared under the revealing influence of the magnetic powder. A more scientific use of the method was shown in the recording of impulses from a cosmic-ray recorder deep underground.

Magnetic tape has been adapted by Marshall of Cambridge Electronics for recording the pulses from nuclear radiation detectors. The output can be played back into a pulse height analyser and a wide range of variation in recording and playback time is possible, a maximum of 80 hours recording being compressed into 24 minutes of playback time. As two channels are available a variety of coincidence measurements is possible, with a minimum of complexity.

It is interesting to see how, given sufficient time, any scientific discovery is turned to good use. The modern application of the Kerr magneto-optic effect has already been mentioned, and three other examples must receive comment. The Peltier effect in metals is very small, but in semiconductor devices it may be much larger. Recent developments in making semiconductors have enabled the effect discovered in 1934 to be turned to practical use. The thermoelectric refrigerator is not yet in commercial production in this country but small cooling units are now available for a variety of purposes and were shown by Joseph Lucas and by the General Electric Company.

Rayleigh pointed out that the Faraday magneto-optic effect permitted the construction of a light-valve through which light could freely pass in one direction but was completely reflected in the other direction. This was an academic curiosity. In 1884 Kundt discovered that films of iron gave enormous magneto-optical rotation; today ferrites are found to give sufficient Faraday rotation to be used as 'circulators'—non-reciprocal phase-shift devices in microwave guides. Measurement of such phase-shift was demonstrated by the Conconi Wireless Telegraph Research Laboratory. Ferrite

elements may be used as isolators, or one-way valves for microwaves, and in fact were so used in the demonstration.

A more recent observation was that of Ranque in 1933 who noted that under suitable conditions air circulating in helical motion in a tube might be made to emerge in two parts, the temperature of one raised above and that of the other lowered below the temperature of the incoming stream. In 1946 Hilsch published a paper on the phenomenon, but the vortex tube as it became known, remained a curiosity until now. The Admiralty Research Laboratory has used it successfully to cool the air supply to a ventilated suit, enabling the wearer to work at a maximum temperature of 80° F in ambient temperatures as high as 180° F.

The Oxford Research Laboratories for Archaeology and the History of Art showed the newest version of their x-ray scanning microprobe equipment, similar to that produced by Associated Electrical Industries. In this an electron beam with a microfocus less than 1 micron in diameter scans the surface under examination, the resulting x-radiation is analysed by a bent crystal spectrometer with counter recording. The integrated output may be fed to a memory-type oscilloscope; the resulting picture of the surface built up on the screen is such that the brilliance of the image at any point is proportional to the local concentration of the particular component selected by the spectrometer. Surface topography may also be seen by examination of the scattered electron optical image built up and displayed in similar fashion.

The free-precession proton magnetometer has been developed for use in archaeological surveys, and is able to indicate buried features of many kinds for it is capable of measuring the magnetic field to 1 part in 10^5 . A new and elegant development of this instrument is the free-precession proton gradient magnetometer. This is ingeniously simple; it uses two detector heads, the audio outputs from which are allowed to beat together. Equivalence of field strength at the two heads is indicated by absence of beats, but simple observation of the beat frequency, when beats occur, gives directly the difference in field strength, and hence the gradient of the field.

It was interesting to see a demonstration by the Atomic Energy Research Establishment, Harwell, of the recently discovered Mössbauer effect, although to be sure the visitor would have had to wait a long time to see for himself that the result of the counting experiment confirmed the theory.

One new development that may be of fundamental importance was shown by Guy's Hospital Medical School. Electron spin resonance has been in use for some 15 years and physics, chemistry and biology have all profited by the technique which is essentially a type of electromagnetic absorption spectroscopy. Substances containing unpaired electrons, paramagnetic elements or free radicals all show marked and characteristic absorption and may be recognized by this means. Largely because the legacy of the last war lay in an abundance of apparatus and technical knowledge relevant to the 3 cm microwave region, it has been to this region that electron resonance spectroscopy has been chiefly confined. Now work has been started at Guy's Hospital in the 1 metre wavelength region. There are many advantages in using the longer wavelength. Because the frequency is so much lower coaxial cables are used in place of waveguides, and the magnetic field required is so much less that a pair of Helmholtz coils suffice instead of the heavy and expensive magnet necessary when working at 3 cm. As the dielectric absorption of water is so much less at the lower frequency samples of high aqueous content can be examined, with considerable extension of usefulness in the biological sphere. The apparatus is therefore cheaper and the hope is that it

will yield new information not attainable by conventional equipment.

Standard Telephones and Cables and Edwards High Vacuum Ltd. showed a variety of evaporated films. By evaporation, electronic components, resistors and capacitors, and even complete circuits may be made. The Royal Radar Establishment, Malvern, and Texas Instruments Ltd. showed a number of such microcircuit assemblies, and also what may be called solid circuits, built out of suitably processed and shaped blocks of semiconducting materials. One such circuit shown was acting as a flip-flop and though it measured only $5\text{ mm} \times 3\text{ mm} \times 0.7\text{ mm}$ it could replace a conventional circuit containing two transistors, four diodes, six resistors and four capacitors. Small size has other uses besides satisfying the topical need to pack much electronic circuitry into the restricted space in rockets and satellites. Obtaining medical and biological data will be facilitated by the production of small transducers, transmitting radio signals from inside the alimentary canal, thus enabling continuous and exact information about the pressure and temperature to be obtained at every point in its passage through the body. These transducers may be obtained from Solartron Electronic Group Ltd. and measure no more than $16\text{ mm} \times 6\text{ mm}$. Surprisingly small as this is, swallowing one of them must require a strong effort and a firm will; it is to be hoped that micro-miniaturization will enable smaller capsules to be made in the near future. The reduction of size during the past year has been significant, but it is not yet sufficient.

There were exhibits in which the phenomenon of epitaxy had been utilized, that is to say the growth of one crystal upon another of like symmetry and crystal spacing, without change of orientation. Silicon transistors made in this way were shown by Texas Instruments and by Standard Telephones and Cables. Such transistors will be suitable for ultra-high-frequency work and fast switching in the 10^{-9} second range. The General Electric Company Research Laboratories showed similar silicon transistors grown by the regrown diffusion process. Doubly doped regions are produced in a pure silicon block by melting and controlled freezing of suitably doped material. Use is made of the expansion of silicon on freezing, and of the contact angle between solid and liquid silicon to produce characteristic conical growths, which are then heat-treated to develop the desired three layer n-p-n structure. The process is simple and very economical of silicon.

Marconi's Research Laboratory have developed a simple method of determining the resistivity of high purity zone-refined silicon without removing it from its sealed dust-protecting polythene bag. The specimen ingot is made one arm of a Schering bridge working at 5 Mc/s, the current being induced in the ingot via the capacitance between it and a pair of encircling metal clips which hold it in position. The range of measurement is such that resistivities of 200 to 3000 ohm cm can be determined with accuracy to about 5%.

The cutting or polishing of single crystals produces work hardening which destroys their regularity; to avoid this electrolytic methods must be used when possible. An electrolytic polisher for this purpose is obtainable from Nash and Thompson.

The production of new materials with unique properties is the aim of some work going on in the Basic Physics Division of the National Physical Laboratory in which materials are subjected to very high pressures. The method employs the tetrahedral anvil first used by H. T. Hall and the National Bureau of Standards, Washington, D.C. Pressures up to 70 000 atmospheres are possible and measurements of the

resistivity of indium antimonide show that there is a dramatic drop in resistivity at a point believed to indicate a phase change, the semiconducting material becoming essentially metallic conductor.

Many microwave amplifiers of various kinds were exhibited but one of a new type was shown by Associated Electric Industries Research Laboratories. It is related to the Adler tube but it uses d.c. electrostatic fields and is not, as it stands, a low noise amplifier. The incoming signal is transferred to an electron beam in an axial magnetic field, so that the electrons rotate with cyclotron frequency as they move forward. An electrostatic quadrupole array amplifies their motion, the process in effect converting some of the kinetic energy of motion along the axis into rotational energy of motion around the axis. Thus no power is taken from the d.c. field in the quadrupole array, but the increased rotational energy is fed into the output coupler, so that amplification of the signal is achieved. The tube, which as yet is only experimental, should be useful in high power continuous wave amplification and in millimetre wave amplification. The methods of cooling the beam are devised it may become usable as a low noise amplifier.

New potentiometers by Tinsley and by Pye are sensitive to 10^{-7} volt and measurements are claimed to be independent of thermal e.m.f.s. Messrs. Tinsley's instrument is designed to be used in conjunction with an automatic current controller which stabilizes a current of 15 mA to 1 part in 10^6 . This enables full use to be made of the precision of the potentiometer, even to the extent of dispensing with the normal period of settling in of a freshly charged accumulator.

Langham Thompson have designed exceptionally reliable regulators with precise performance, having no moving parts or thermionic valves, and fast response. The circuits employ saturable core transformers with the d.c. windings activated by feedback circuits from the output of an auto transformer. The control circuits are completely transistorized; voltage regulation is claimed to be to 0.01%.

This year even more instruments are provided with digital display instead of pointer readings. Venner Electronics and Racal Instruments show frequency meters, Ferranti Ltd., Nash and Thompson, and Solartron Electronic Group exhibit volt- and ohm-meters, the ingenious system shown by Sangamo Weston being popular. In this the stepped outputs are fed to a series of galvanometers. The pointers do not move over scales, but each carries a quadrant of a cylindrical transparent scale bearing the digits 0 to 9 moving in front of the field stop in a simple projection system. An enlarged image of the digit appears on a translucent screen. The device is simplicity itself, and must substantially reduce the cost of digital display.

In conclusion it may be said that in the opinion of the reviewer the exhibition was one of the more successful at the standards of exhibits was high. There were perhaps fewer exhibits from University and Research establishments than might have been desired; these exhibits come in a random distribution, and so long as next year's entry is larger there is no great cause for disquiet, as there was a few years ago. The exhibits were remarkable for their general interest and topicality—in other words they were of new apparatus and technical processes, relevant to the recent trends of research and development. Unstinted praise is due, as always, to the organizers, and in particular to the editor of the catalogue, which is of the high standard of production we have come to expect.

The entries for the Craftsmanship and Draughtsmanship Competition were displayed in the vestibule of the New Hall.

firms and research establishments participated and the entries commented that, disappointingly small as the entry for this year, the standard had been maintained and in some respects improved on previous years. The entries were as follows:

Silvanus P. Thompson Prize	3	
Scientific Instruments and Components		
(a) Junior	7	
(b) Senior	10	
Optical Components and Systems	4	
Blown-glass and Silica Ware		
(a) Blown-glass	5	
(b) Silica	4	
Instructional Items, Sections of		
Instruments	7	
Microwave Components	3	
Electronic Circuitry		
(a) Junior	3	
(b) Senior	4	Total 50

The first prizes in Class II(a) and (b), III and V were given as a donation from the Bowen Trust Fund by the Scientific Instrument Manufacturers' Association. Mr. G. C. Ottway, President of S.I.M.A., attended the Prizegiving and presented the Bowen Prizes.

The other prizes were presented by Dr. J. Topping, Chairman of the Education Committee, under whose auspices the Competition will come now that the Institute and Society have amalgamated.

A special prize was awarded in Class V for a Sixteenth-Century Assayer's Balance, which was entered under the Science Museum's scheme for setting up a Historical Section; firms had been informed of the Museum's need for reproductions of early pieces of apparatus and it had been arranged that any suitable should be included in the Competition.

Stabilization of thermometers of borosilicate glass for use at high temperatures

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Abstract

An investigation has been made into the best heat-treatment to be given to thermometers of borosilicate glass before graduation, in order to secure good stability in use at temperatures between 400 and 500° C. Zero rises of less than 0.1 deg C per 100 h at 460° C have been achieved by a stabilization treatment consisting of cooling from 570 to 410° C in not less than 400 h. No shorter treatment gave as good a result if the thermometers were used above 410° C. A comparison is made of the performances of three glasses, of German, American and English origin.

1. Introduction

EXPERIENCE at the National Physical Laboratory and in the laboratories of some large users of mercury thermometers suggests that the zeros of high-range thermometers made recently have not been as stable as those of similar thermometers made before the war. For example, at the N.P.L., thermometers of Jena borosilicate glass (59''' or 2954''' according to date), graduated up to 400° C and put into service in 1929 and 1937, showed rises of zero ranging from 0.7 deg C to 1.4 deg C over periods of twenty years or so in regular use. It is not possible to give exactly the number of hours for which these thermometers were heated to the maximum temperature, but it would be of the order of 100 h a year. On the other hand, a batch of similar thermometers made in 1952 of 2954''' glass, by the same man, showed a rise of about 1.5 deg C after only 210 h heating at 410° C (Fig. 1, curve 1). Replacement thermometers supplied in the following year (curve 2) showed some improvement, and when the heating had been con-

tinued for 2700 h and the zeros had risen nearly 3 deg C, thermometers were satisfactorily stable.

In order to determine whether similar effects would be experienced with German-made thermometers of the same glass, we examined two batches of German thermometers made in 1949 and 1953, which were put at our disposal through the kindness of the Central Laboratories of the Shell Petroleum Company. The results obtained are shown in curves 3 and 4 respectively.

2. Annealing above the transformation temperature

In view of the above results, it was decided to undertake an investigation to determine the best heat-treatment for high-range thermometers before graduation. Dr. R. H. of the Physikalisch-Technische Bundesanstalt, communicated to us the recommendations of Messrs. Schott and Genco, the makers of the 2954''' glass. They gave the transformation temperature* as 570° C and the maximum usable temperature as 525° C, and recommended that the glass should be annealed for about 6 h at about 30 deg C above its transformation temperature. It should then be allowed to cool at a rate of about 0.1 deg C per minute to a temperature some 100 or 100 deg C below the transformation temperature. Then after it could be cooled rapidly.

Our first experiments were based on this information. Two thermometer makers co-operated with us by each making three groups of thermometers which had been heated various times at 570, 585 and 600° C. All the thermometers were cooled slowly to 500° C, maker A using a rate of about 1 deg C per minute and maker B about 0.2 deg C per minute. Subsequent experience has shown that the different times of heating were probably insignificant, and it would not be worth attempting to deduce more from these experiments than can be seen from the mean zero rises given for each annealing temperature in Table 1.

Table 1. Zero rises of thermometers of Jena 2954''' annealed at 570, 585 and 600° C

Duration and temperature of heating	Zero rise (deg C) produced by each period of heating					
	Annealing temperature and maker					
	570° C (A)	585° C (A)	600° C (A)	570° C (B)	585° C (B)	600° C (B)
683 h at 400° C	2.6	3.3	3.3	2.5	2.6	2.7
552 h at 500° C	3.4	7.9	5.7	10.4	12.2	12.2

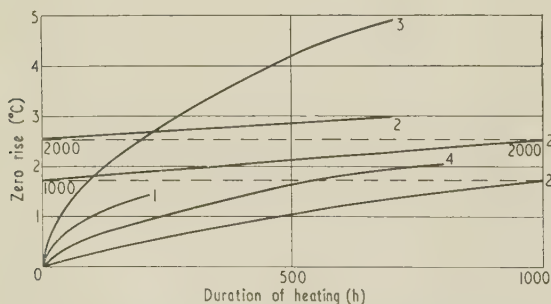


Fig. 1. Stability of commercially produced thermometers

Curve 1, English 1952 } heated at 410° C.
Curve 2, English 1953 }
Curve 3, German 1949 } heated at 400° C.
Curve 4, German 1953 }

The zero rises, after prolonged heating at 400° C, of thermometers which had been annealed at 570° C, correspond to the values in Table 1.

* The transformation temperature is indicated by the bend in the expansion curve of the annealed glass (see Fig. 7). At points on the curve below this temperature the glass is not in equilibrium.

ly to those given by curve 1 of Fig. 1, and it is known the thermometers to which this relates were also annealed 0° c. Annealing at 585 or 600° c has led to somewhat or results. The marked differences between the further rises of the two makes of thermometer when they were frequently heated for 552 h at 500° c may be due to differences in pressure of gas-filling. If the gas pressure is there is a tendency for the glass to flow under pressure, at the bulb is permanently enlarged, thus neutralizing some extent the normal rise of zero. It is known that maker B uses a low gas pressure (the lowest curve of Fig. 2 presents his normal practice), but we have made no measurements of the gas pressure in maker A's thermometers.

3. Stabilization at the working temperature

is necessary to draw a distinction between the annealing of glass and its stabilization. The procedures which have been described provide adequate annealing; that is, they relieve stresses in the glass which might lead to subsequent fracture. For a thermometer, however, we need something more than this: we need the glass in a condition which is stable at the temperature at which it is to be used, so that it will have little or no tendency to change its dimensions when maintained at that temperature. In other words, the glass should be, as nearly as possible, in equilibrium.

When a glass is heated to its transformation temperature or above, it will rapidly take up the configuration (equilibrium configuration) appropriate to the temperature. On slow cooling, the glass is at first of sufficiently low viscosity for the configuration to change appropriately, until at some lower temperature (the slower the cooling the lower this temperature will be) the glass becomes too viscous for the configuration to change at a rate corresponding to the rate of cooling, and the configuration which is stable at that temperature becomes frozen in. This temperature is referred to as the 'fictive temperature'.

Therefore, a glass is brought suddenly to its fictive temperature it will find itself in equilibrium and there should be no tendency for it to change its volume. If, however, it is brought to a slightly lower temperature and that temperature is maintained, the glass will slowly change its configuration towards that which would be stable at the lower temperature. This change is in the direction of increasing density of the glass, so the bulb of a thermometer used at this temperature would contract and the zero rise. Conversely, if a thermometer is maintained at a temperature somewhat above the fictive temperature of the glass we would expect the zero to fall.

The behaviour of the thermometers is complicated by the presence of delayed elastic effects, which are particularly marked with borosilicate glasses, and of changes in viscosity with fictive temperature. Nevertheless, it would seem to be possible to make the fictive temperature of the glass correspond fairly closely with the temperature at which it is to be used. Since changes due to lack of equilibrium will be rapid at higher temperatures, it is probably best to bring the glass to equilibrium at the highest temperature at which the thermometer will be used.

This end might be achieved in two ways: first, by cooling the glass to the transformation temperature at a rate chosen so that the configuration would cease to change when the desired fictive temperature was reached. If the rate were slower than this, the same result would be achieved if the glass were cooled rapidly on reaching this temperature. Secondly, the glass could be held for a prolonged period at

the desired fictive temperature; a period which would have to be very long if the required temperature were much below the transformation temperature (for example, see Fig. 1, curve 2). In the experiments now to be described, we tried the slow-cooling method first, and when the time necessary to secure adequate stability by this method had been determined, we experimented with various constant-temperature treatments in order to see if comparable stability could be achieved in a similar time.

4. Experimental method

The thermometers. Unfilled thermometer blanks, consisting of a bulb with an open-ended capillary, were supplied by three manufacturers. They were given various stabilizing heat-treatments and returned to the makers for filling, with a request that re-heating of the bulbs should be kept to a minimum. It is necessary to boil the mercury in the bulb, so that all the thermometers will have been heated to about 370° c after stabilization. The thermometers were pointed at 0 and 100° c only and the scale was then extrapolated so as to avoid further heating during manufacture. Expansion chambers were provided to permit subsequent heating to 500° c.

The thermometers were identified by numbers of the following type: BJ570/395/410/R2. The first letter indicates the maker (B, C or D) and the second the glass (J = Jena 2954''', C = Corning borosilicate and P = Powell's white-stripe borosilicate). The first number gives the initial temperature of the stabilization treatment, the second its duration in hours and the third the final temperature. The subsequent cooling to room temperature is indicated by the letter R for natural cooling in still air or S for cooling in the furnace at a rate of about 12 deg c per hour. No difference was detected between the performance of corresponding thermometers in the R and S series. The final number serves to identify different thermometers which have received identical treatments.

Gas pressure. As it became clear in the course of the work that the gas pressure in a thermometer had a considerable influence on its stability when used at high temperatures, experiments were made to determine approximately the gas pressures in typical thermometers. Four thermometers from the series XX570/469/460/XX were used: one was made by maker C, one by maker D and two were made by maker B using different methods. Thermometer BJ-R1 was filled at atmospheric pressure at a temperature a little below atmospheric and was provided with an expansion chamber sufficiently small for the pressure to rise to suitable values as the gas was compressed by the rising mercury. Thermometer BJ-S1 was filled at a pressure of 20 atm, but had a much larger expansion chamber.

The internal pressure of each of the four thermometers was measured with the mercury standing at 20° c by immersing the bulb of the thermometer in a small Dewar vessel containing water at that temperature, breaking off the top of the thermometer, noting the rise of reading and then applying a series of pressures in order to determine the excess above atmospheric pressure necessary to annul the rise. The volume of the upper end of the thermometer which had been broken off was determined by weighing mercury in it, and the scale value of the top of the bore was thus determined. The gas pressures developed by the rising of the mercury were then computed, assuming the gas to remain at 20° c, and plotted in Fig. 2. The actual pressures in normal use might be anything up to about 50% higher than those

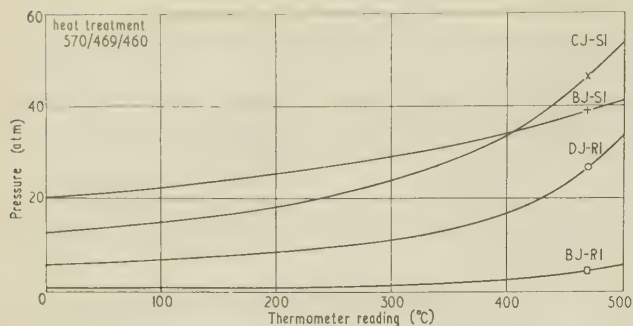


Fig. 2. Internal gas pressure in typical thermometers.

plotted for the higher temperatures, since the gas temperatures will certainly rise considerably. In the present work the thermometers were heated horizontally and a considerable length of column was outside the furnace, so that the gas pressures are not likely to have been more than about 10% greater than those of Fig. 2. The internal pressure coefficients determined during these measurements were about 0.10 deg c/atm for the thermometers of makers C and D and about 0.07 deg c/atm for those of maker B.

Stabilizing heat treatments and results (Jena 2954'' glass). All the heat-treatments using slow cooling started at 570° c and are shown in Fig. 3. The first to be tried was the one

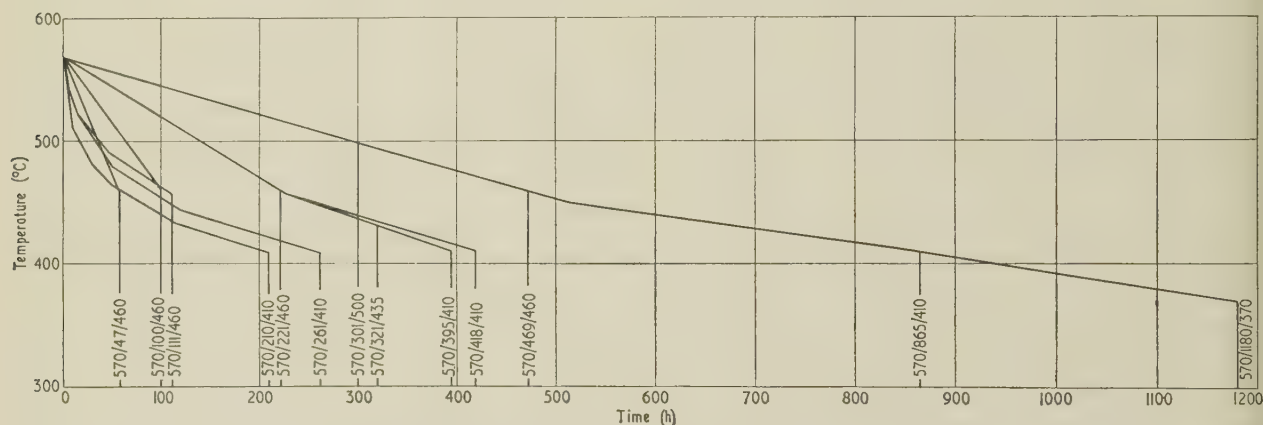


Fig. 3. Various stabilizing heat-treatments using slow cooling from the transformation temperature.

finishing at 370° c after 1180 h cooling. It was hoped that at this slow rate the configuration of the glass would be able to follow the cooling throughout, and thermometers were withdrawn intermediately at 500, 460 and 410° c.

The results of the subsequent stability tests on the thermometers of Jena 2954'' glass in this series are shown in Fig. 4. The 'zeros' of the thermometers after each period of heating were, for convenience, taken at 20° c by comparison with standard thermometers in a water bath. The changes of zero plotted in Fig. 4 and the subsequent graphs (except Fig. 8) are related to the zero at the end of a first heating period of 24 h (the period normally adopted for a 'permanence of range' or 'bulb stability' test). This has been done because the zero depends on the rate of cooling of the thermometer after its previous heating (Van Dijk, Hall and Leaver 1958), and whereas the cooling at the end of manufacture was not controlled, all subsequent cooling was carried out at a rate not exceeding 25 deg c per hour, this having been shown to be sufficiently slow to suppress

completely the temporary depression of zero (Van Dijk Hall and Leaver 1958).

It is clear from the effect of heating for just over 1000 h at temperatures ranging from 370 to 460° c on the thermometers of which the slow cooling had continued down to 410 or 370° c, that these thermometers are very satisfactorily stable, provided that they are not used above 460° c. The thermometers on which the stabilizing treatment had been cut short at 460° c were somewhat less good, though possibly acceptable. When the thermometers were heated to 500° c none of the heat treatments was found to be really satisfactory, and the behaviour of the thermometers became very dependent on the internal gas pressure. The curves for the heat-treatments 570/865/410 and 570/1180/370 show this very clearly. Since the thermometers were only partially immersed, the reading for a temperature of 500° c was about 470° c. The curves of Fig. 2 have been marked at this temperature with the same symbols as have been used for the corresponding thermometers in Fig. 4, and the correlation between pressure and the fall of reading which occurs between about 1100 h and 1700 h is clear. Confirmation of this result was sought by having one of maker B's blank-filled, after heat-treatment, by maker C. The results obtained with this thermometer, marked BCJ570/321/435/R2, are shown in Fig. 5, and they correspond very closely with those for the thermometer CJ570/321/435/R1, showing that the

determining factor was the work done by maker C, i.e. the filling. We should expect a slightly smaller fall with thermometer BCJ than with thermometer CJ, since the pressure coefficient of maker B's thermometers had been found to be rather lower than those of maker C, and there is, in fact, a just detectable difference in this sense. It is hardly significant, however, as it could also be accounted for by a slight difference in gas pressure.

In studying these curves it must be remembered that unless the glass is being heated at its fictive temperature its configuration will be continually changing during the stability tests. Not only that, but the behaviour of the glass will be affected by delayed elastic effects which will depend on its thermal history. If the fictive temperature were the only factor concerned we should expect the zero to fall when the thermometer was heated at a higher temperature. Such a fall does, in fact, occur with both high- and low-pressure thermometers in the series 570/469/460 and 570/865/410 c Fig. 4 when they are heated to 500° c, but when this heating

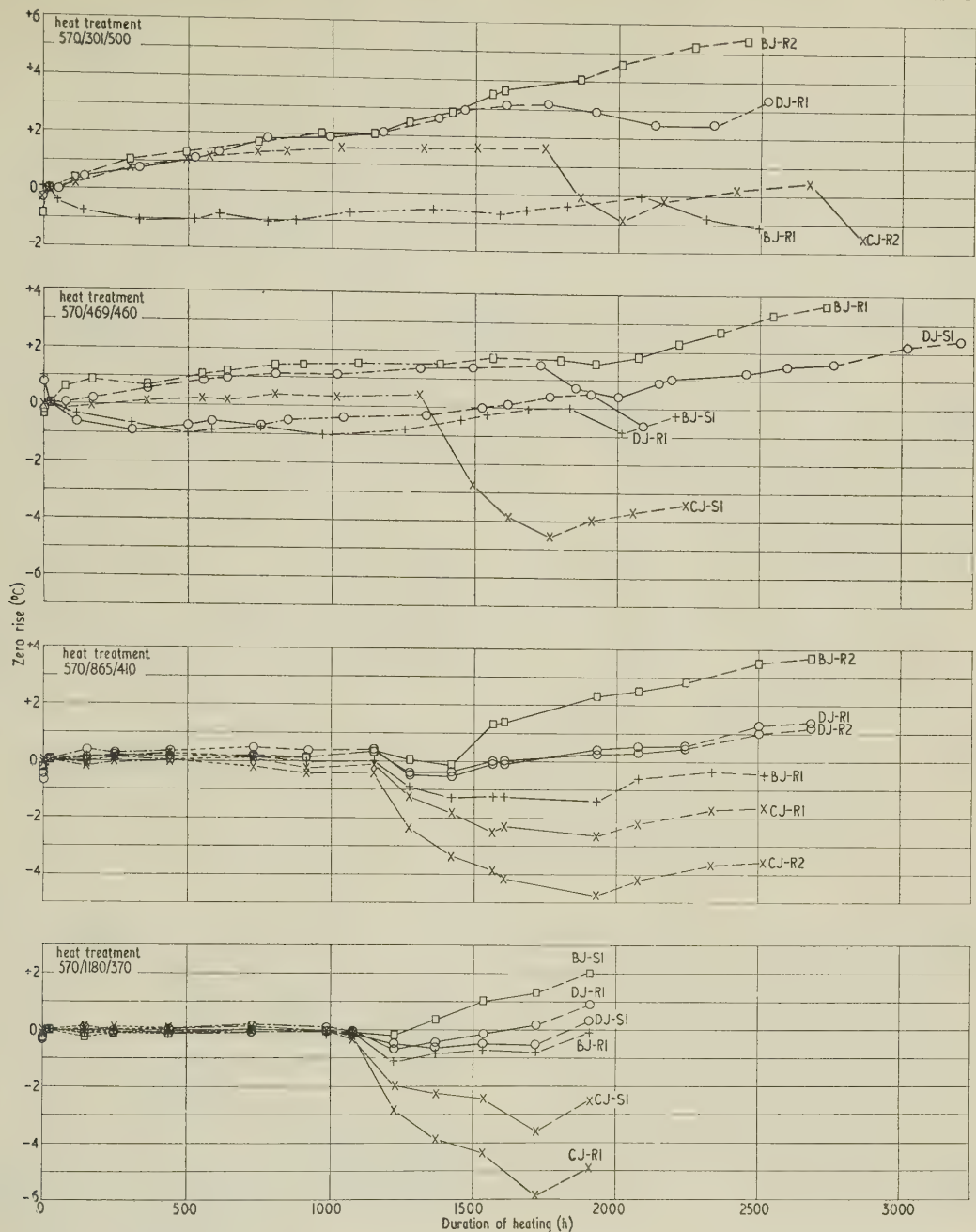


Fig. 4. Zero stability of thermometers of Jena 2954'' glass stabilized by slow cooling from the transformation temperature.

s place after a considerable period at 410 or 460° c, the al fall in the low-pressure thermometers is converted into e after about 200 h at 500° c. It has been suggested t at this is almost certainly due to a delayed elastic effect. ny event, it is clear that heating to 500° c has had a erious effect on stability, since the thermometers of the 865/410 series, which showed almost perfect stability re they were heated to 500° c, subsequently showed a

rise of about 0.2 deg c/100 h when they were reheated at 460° c. For the highest accuracy, therefore, the thermo- meters should never be heated above 460° c. The next step was to investigate the possibility of shorten- ing the time required for stabilization. Fig. 5 shows the effect of increasing the rate of cooling to 460° c approximately 2, 5 and 10 times. These results, together with those of all the other experimental treatments, are summarized in

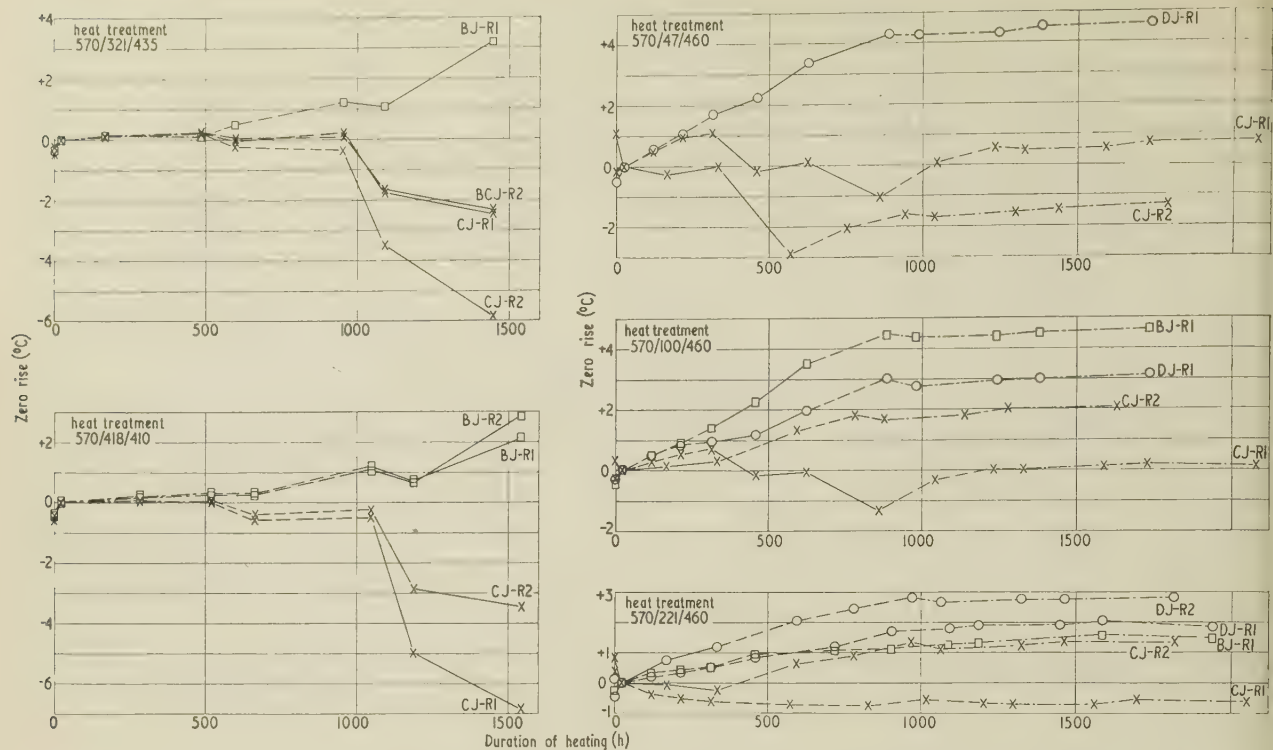


Fig. 5. Effect of using different cooling rates on the zero stability of thermometers of Jena 2954''' glass.

□ Maker B } low gas pressure — · — · — 410° c
○ Maker D } — — — — — 460° c
× Maker C: high gas pressure — · — · — 500° c

Table 2 which gives the zero rises in degrees c per 100 hours heating at 460° c for the four cooling rates as 0.15, 0.20, 0.50 and 0.60 deg c as the rate is increased. Clearly, doubling the rate had had little effect, but faster rates cannot be tolerated. The figures in Table 2 must be used with some caution, since the order in which different temperatures were used in the stability tests was not always the same, so that the figures may not be strictly comparable. The rates of rise have usually been estimated over a period of about 500 h, over which the uncertainty is about ± 0.2 deg c, so that an uncertainty of ± 0.04 deg c/100 h is to be expected in the figures of Table 2.

Table 2. Summary of effects of different stabilizing heat-treatments on thermometers of Jena 2954''' glass with low gas pressures

Type	Heat-treatment		Approximate rate of rise of zero (deg c/100h) as a result of heating at		
	Time and temperature*		410° c	460° c	500° c
First series (slowest cooling)	570/301/500	0.10	0.18	0.20	
	570/469/460	0.06	0.15	0.30	
	570/865/410	0.04	0.03	0.25	
	570/1180/370	0.00	-0.05†	0.30	
Second series (cooling rate approximately doubled)	570/221/460	0.05	0.20	—	
	570/321/435	0.02	0.20	0.55	
	570/395/410	0.06	0.08	—	
	570/418/410	0.05	0.15	0.50	

Type	Heat-treatment		Approximate rate of rise of zero (deg c/100h) as a result of heating at		
	Time and temperature*		410° c	460° c	500° c
Third series (about 5 and 10 times slowest cooling rate)	570/100/460	0.08	0.50	0.60	
	570/47/460	0.07	0.60	0.60	
Fourth series (final rate as in second series, initial rate much faster)	570/111/460	0.10	0.29	0.80	
	570/261/410	0.08	0.30	0.80	
	570/210/410	0.12	0.75	1.0	
Fifth series (constant temperature)	540/321/540	0.24	0.48	0.80	
	520/321/520	0.14	0.30	0.60	
	500/395/500	0.24	0.30	0.75	
	500/221/500	0.20	0.30	—	
	460/221/460	0.20	1.1	ca. 4	
	460/100/460	0.32	2.1	ca. 5	
German commercial production (1949) (1953)	Unknown	1.5‡			
		0.5‡			
English commercial production (1952) (1953)	Unknown	1.0			
		0.2			

* The three figures are initial temperature/time/final temperature.
† Uncertain: based on 91 h heating only.
‡ Heated at 400° c only.

The effect of shortening the time taken to cool to 410° c from 865 h to about 400 h has somewhat impaired the stability at 460° c, but it is still better than when the 400° c

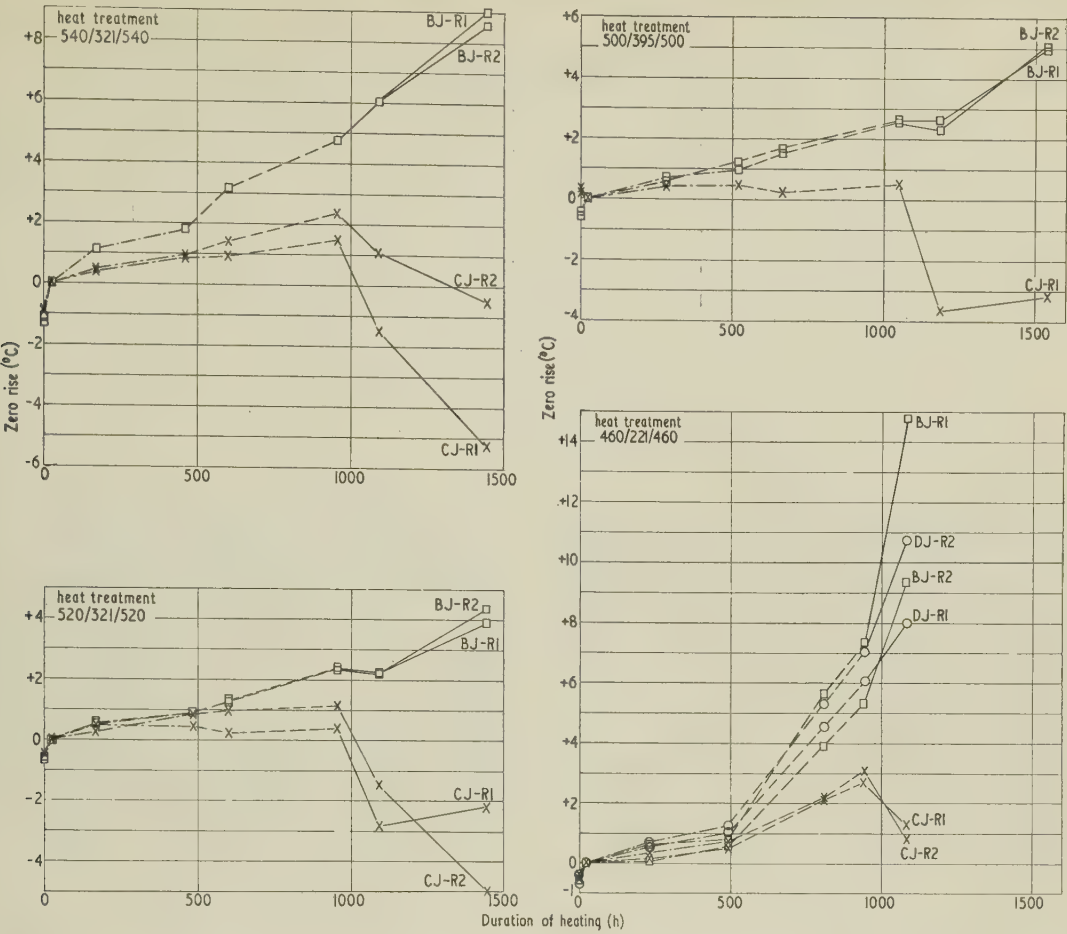
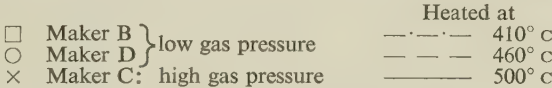


Fig. 6. Zero stability of thermometers of Jena 2954''' glass stabilized by prolonged heating at a constant temperature.



was cut short at either 460° C (221 h) or 435° C (321 h), can be regarded as acceptable. The difference of 0.07 between the figures quoted for the two treatments 570/395/410 and 570/418/410, which should have given almost identical results, is in accordance with our estimate of the uncertainty in the results. The second treatment was carried out as a replacement of the first, of which the thermometers were accidentally destroyed. Only the results obtained with the replacement thermometers have been plotted in Fig. 5. No experiments have been made to see if halving the 301 h of 570/301/500 treatment would make any difference to the stability at 500° C, but the inference from the above experiments is that some shortening of the time would be permissible. As it seemed likely that time was being wasted through unnecessarily slow cooling at the higher temperatures, experiments were made to see if increasing the rate of cooling above 480° C would give a satisfactory result. The results are shown in Fig. 3 as 570/111/460, 570/261/410 and 570/210/410. The results obtained after heating at 460° C are given in Table 2 and are much inferior to those obtained by cooling to 410° C in about 400 h.

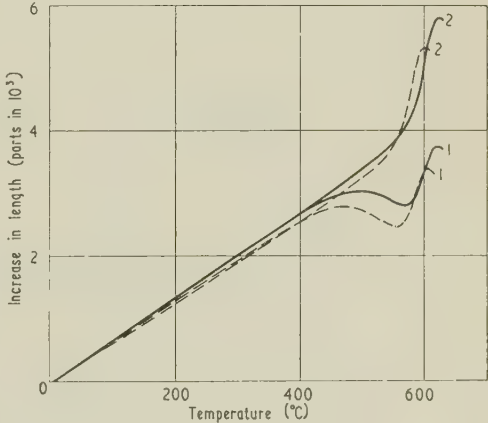
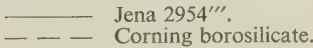


Fig. 7. Expansion curves: heating rate 2 deg C/min. 1, unannealed; 2, annealed.



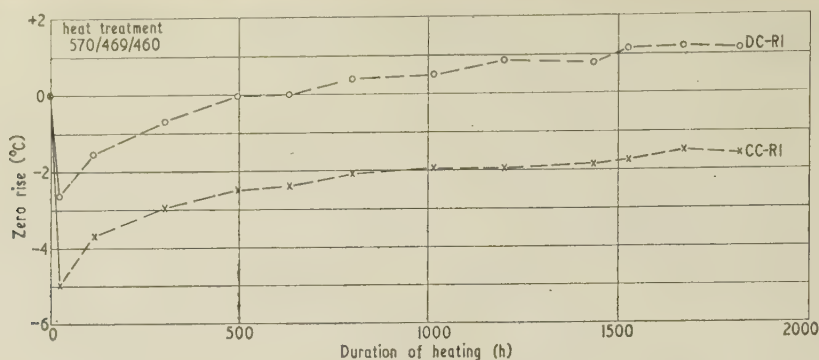


Fig. 8. Effect of heating Corning borosilicate glass to 500° C.

× Maker C (high gas pressure) — — — 460° C
 ○ Maker D (low gas pressure) — — — 500° C

Having established that satisfactory stability could be achieved in a period of about 400 h by slow cooling, experiments were next made to see if heating at a constant temperature for a comparable length of time could be made to yield a similar result. Such a heat-treatment might be more convenient in the manufacture of thermometers, as a simpler temperature controller could be used. Curve 2 of Fig. 1 shows that at 410° C a period of some 3000 h would be necessary to achieve reasonable stability, but a higher soaking temperature might lead to a sufficiently low fictive temperature. Fig. 6 shows the results of four experiments, and it is clear that the stability obtained is not as good as with any of the slow coolings of the first two series, even though one of them lasted only 221 h (see Table 2).

Comparison of different glasses. Expansion curves obtained at the University of Sheffield for both Jena 2954''' and Corning borosilicate glass are shown in Fig. 7. The curves show that the transformation temperature for the Corning glass is about 15 deg C lower than for the other. Fig. 8 shows the effect of heating at 500° C for 24 h on two thermometers of Corning glass which had had the treatment 570/469/460. The zero of a thermometer with low gas pressure (DC-R1) fell 2.7 deg C, and that of one with high pressure (CC-R1) fell 5.0 deg C. Some of the high-pressure thermometers exploded in the furnace. It is clear that the glass has flowed much more than did 2954''' under similar conditions. After having been heated at 500° C, both thermometers show a rise of about 2.5 deg C in the first

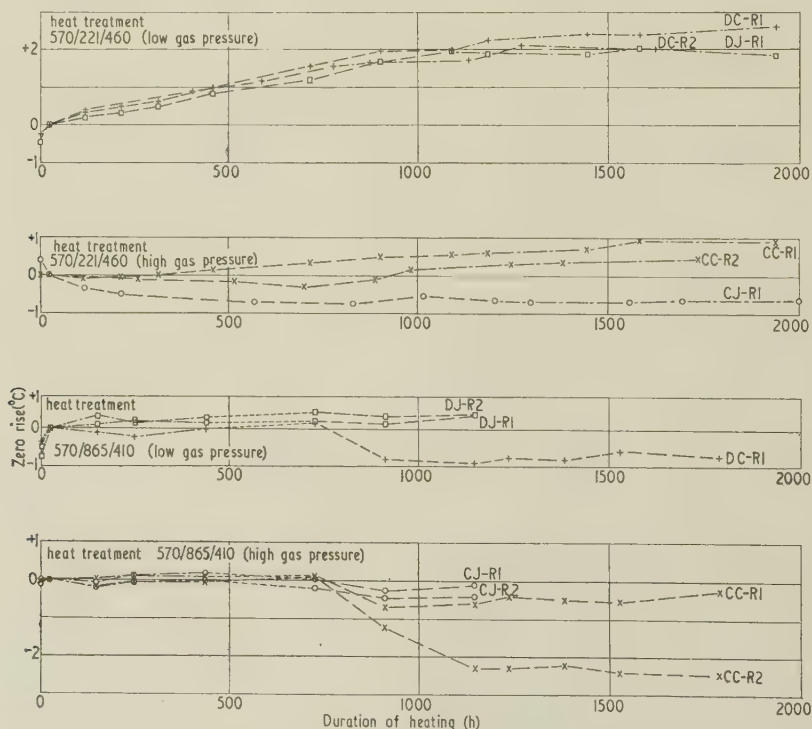


Fig. 9. Comparisons of Jena 2954''' and Corning borosilicate glass.

High gas pressure Jena ○ Corning × Heated at
 Low gas pressure Jena □ Corning + — — — 370° C
 — · — 410° C
 — — — 460° C

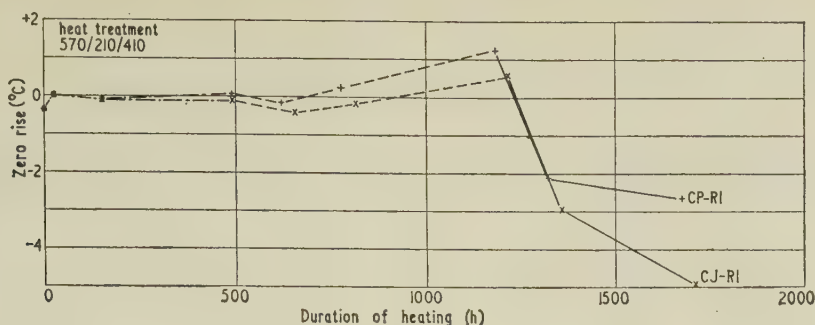


Fig. 10. Comparison of Jena 2954''' (x) and Powell's white-stripe (+) glass.

Heated at
 - - - - - 410° C
 - - - - - 460° C
 ————— 500° C

of subsequent heating at 460° C, whereas Fig. 9 shows with the treatment 570/221/460 and without prior heating to 500° C the rise is about 1 deg C. Comparison of 4 and 5 shows that the difference between the two treatments is insignificant in effect, even for the harder glass, so it seems clear that the 24 h at 500° C has appreciably raised the fictive temperature of the Corning glass. Reference to Fig. 4 shows that the behaviour of Jena glass is much less affected by prior heating to 500° C. This is understandable as the Jena glass is obviously more viscous at this temperature. Fig. 9 shows little difference in behaviour between the two glasses after the heat-treatment 570/221/460, provided that the working temperature does not exceed 460° C, but it seems that the fictive temperature is rather too high as the low-pressure thermometers show an excessive rise of zero. When we consider the performance after the heat-treatment 570/865/410, which has subtly yielded a lower fictive temperature, we find that either low or high gas pressure (maker D or maker C) Corning glass shows a fall of zero relative to 2954''' when heated at 460° C.

Towards the end of the work, an English borosilicate glass, Powell's white-stripe, became available, and the opportunity was taken to compare this glass with Jena 2954''' in some of the later experimental treatments. Fig. 10 shows a typical comparison between two similar thermometers made by the two makers (C). It is clear that there is no serious difference between the performances of the two glasses: such differences where there are could easily be accounted for if the gas pressure in the thermometer of Jena glass were slightly greater than in the other.

5. Conclusions

The following conclusions have been drawn from the above experiments:

Thermometers of Jena 2954''' glass can show good stability at temperatures up to 460° C. The best results are obtained by stabilizing the glass by slow cooling from 570° C. The cooling rate should not exceed 0.5 deg C/h above 450° C and 0.25 deg C/h below that temperature. Some improvement in performance is obtained if these rates are halved. Slow cooling should be continued to 410° C. Stability will be impaired if the completed thermometers are heated above 460° C.

If the thermometer is not to be used above 410° C, the cooling may be stopped at 460° C. If the cooling rate is increased to 2 deg C/h there is only slight impairment of stability at 410° C.

(iii) Thermometers of 2954''' glass are not very stable in use at 500° C, and their behaviour varies considerably with the internal gas pressure, which should be kept as low as possible, consistent with reliable action of the thermometer. Such thermometers may be stabilized by cooling from 570° C to 500° C in 300 h (or possibly a shorter time, though this has not been directly confirmed experimentally), but they will not then be as satisfactory at 460° C as thermometers treated in accordance with recommendation (i). In any case, close watch must be kept on the zeros of thermometers used above 460° C.

(iv) Powell's white-stripe glass may be regarded as equivalent to Jena 2954'', but Corning borosilicate is not suitable for use at 500° C in any circumstances.

(v) It would be advantageous, in addition to the above treatments, to heat a thermometer to the maximum temperature of its range for at least 48 h after filling and before pointing. Cooling from this temperature should take at least 15 h (Van Dijk, Hall and Leaver 1958).

Acknowledgments

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Reference

VAN DIJK, S. J., HALL, J. A., and LEAVER, V. M., 1958, *J. Sci. Instrum.*, **35**, 334.

High-sensitivity recording optical density meter

by K. E. COLLINS and D. J. STEELE, The British Coal Utilisation Research Association, Leatherhead, Surrey

MS. received 29th December 1960

Abstract

A recording optical smoke meter is described which has a high sensitivity. The optical density of smoke in a flue is compared by photoelectric means with that of an optical wedge, which is then rotated by an electrically operated servo-system until the two densities are the same. The angular position of the wedge is detected by a transducer, which provides a millivolt output proportional to the rotation of the wedge.

A multi-channel switching unit, electrically coupled to a recorder, is incorporated; this enables any number of different flue units, up to the capacity of the recorder, to be used or other variables to be recorded at the same time. The range of the instrument can be varied by changing the value of the optical wedge in the balancing unit or by varying the transducer output to obtain full-scale deflection of the recorder for any desired rotation of the wedge.

The calibration in terms of millivoltage output against optical density is linear, provided that the optical wedge and output transducer have linear characteristics. The output is stable to $\pm 0.6\%$ of full-scale reading for ambient temperature changes in the range of $55-80^{\circ}\text{F}$, and the sensitivity is such that densities of the order of 0.005 can be recorded.

1. Introduction

DURING experimental work with solid fuel burning appliances, the need arose for a sensitive optical density meter for smoke measurement in domestic flues. It was required that the instrument should have the following features in order to give maximum flexibility of operation:

- (i) it should give an electrical output suitable for recording on any standard potentiometric recorder, on which it should be possible to record other variables at the same time;
- (ii) the output (millivolts) should vary linearly with optical density;
- (iii) it should enable optical densities over the range 0.1 to 2.0 to be continuously recorded and it should be possible, by means of some simple adjustment, to select any portion of this range to give full-scale deflection on the recorder;
- (iv) the speed of response to changes in optical density should be such as to enable full advantage to be taken of the high speed electronic recorders available, i.e. about one second for full-scale deflection;
- (v) the one meter should be capable of being used in conjunction with a number of flues simultaneously;
- (vi) the stability should be within $\pm 1\%$ of full scale over periods of twelve hours.

A study of commercially available smoke density recorders conforming to the British Standard Specification 2811: 1957 led to the conclusion that they would have neither the sen-

sitivity nor the flexibility of operation to meet the requirements. An improved type of optical density meter, using an optical wedge and an electro-mechanical balancing system, has been described by Bredl and Marsden (1950, B.C.U.R.A. Information Circular No. 29), but, although satisfactory in many respects, the meter was sluggish in operation and insufficiently sensitive to record small changes in optical density. Greater sensitivity is possible by the use of an electronic balancing system, as employed in the meter described by Littlewood (1956), but this instrument was unable to meet the requirements as to flexibility of operation.

The meter forming the subject of the present paper meets the requirements as stated above. It is based on the instrument described by Bredl and Marsden, which has been used at the British Coal Utilisation Research Association for many years, and employs the same flue unit with only slight modifications.

2. Principle of operation

A light beam is projected across a flue on to a barrier layer photocell, the output of which is compared with that of a separately illuminated reference cell situated in a servo amplifier unit. Changes in light intensity at the flue unit photocell, due to smoke density variations, are automatically balanced by rotation of an optical wedge in the light path to the reference cell, until the output of both cells is the same. A voltage signal, obtained from a transducer which rotates with the wedge, can be applied to a standard potentiometric recorder enabling a constant record of wedge positions and hence, optical density to be obtained.

The use of two lamps and photocells might be thought to give an inferior performance as regards stability compared with a system such as that described by Littlewood (1956) which employs only a single cell and a split light beam. This system has its disadvantages however, because of the difficulties associated with the use of a light guide, and it has been found to give no greater stability than is possible with the double lamp and photocell system. The latter was therefore preferred, since it does not require the mounting of the balancing unit on the flue itself.

The use of a system employing an optical wedge enables a linear relationship between optical density and electrical output to be obtained. The range of the meter can be simply altered by interchange of the optical wedges and/or by varying the voltage output for a given angular rotation of the wedge. Increased stability and sensitivity is obtained by rigid mechanical construction of the flue unit, stabilized lamps, temperature-controlled photocells and high-gain amplifier and servo-system.

Flue unit

A schematic drawing of this unit is shown in Fig. 1(a). A 48 watt 12 volt pre-focus bulb under-run at 6 volts

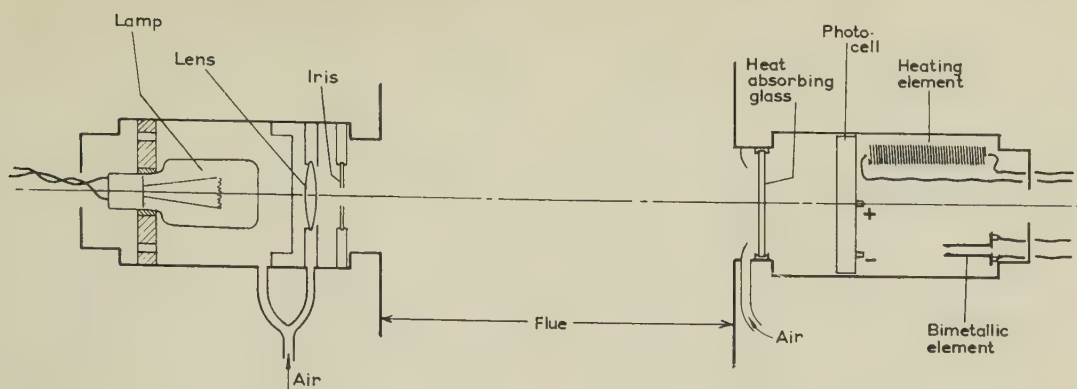


Fig. 1(a). Flue unit.

tained in a housing, designed to allow forced cooling of bulb. To ensure that mains voltage variations do not adversely affect the filament colour temperature, the supply voltage is derived from a constant voltage transformer. A simple lens system produces a slightly divergent beam of light, which passes across the flue and illuminates a barrier photocell mounted in a thermostatically controlled housing. An iris diaphragm is mounted in front of the lens to enable an adjustment of the illumination of the photocell to be made under no-smoke conditions. Heating of the cell due to thermal radiation from the lamp is eliminated by the use of a heat-absorbing glass filter in the photocell unit. There is a tendency, under conditions of high smoke concentration, for smoke deposits to accumulate on the surface of the lens or filter. This has largely been overcome by providing warm air across the respective surfaces and out into the flue. The flue unit is designed so that the lamp and photocell can be swung through an arc to a 'light-tight' tube on the side of the flue, thus enabling a check on any possible drift due to this cause to be carried out during a test

period. Initial balancing of the lamps or correction for drift can be made by adjusting the iris diaphragm.

Servo-motor unit

The servo-motor unit (Fig. 1(b)) comprises a servo-motor, optical wedge, angular displacement transducer, automatic gain control, lamp and photocell. The wedge, transducer wiper arm and gain control are all fixed to the same shaft, which is driven through a friction clutch and 80 : 1 reduction gears by the servo-motor. The angular rotation of the optical wedge is limited by adjustable stops, to prevent the wedge being driven beyond the limits of the graded neutral deposit. The optical wedge and photocell are housed in a light-tight box together with a transistor circuit, which supplies a constant potential to the slide wire of the displacement transducer. The lamp and lens system is similar to that used in the flue unit, the voltage supply to the lamp being derived from the same constant voltage transformer used to supply the flue unit lamp. An iris diaphragm is

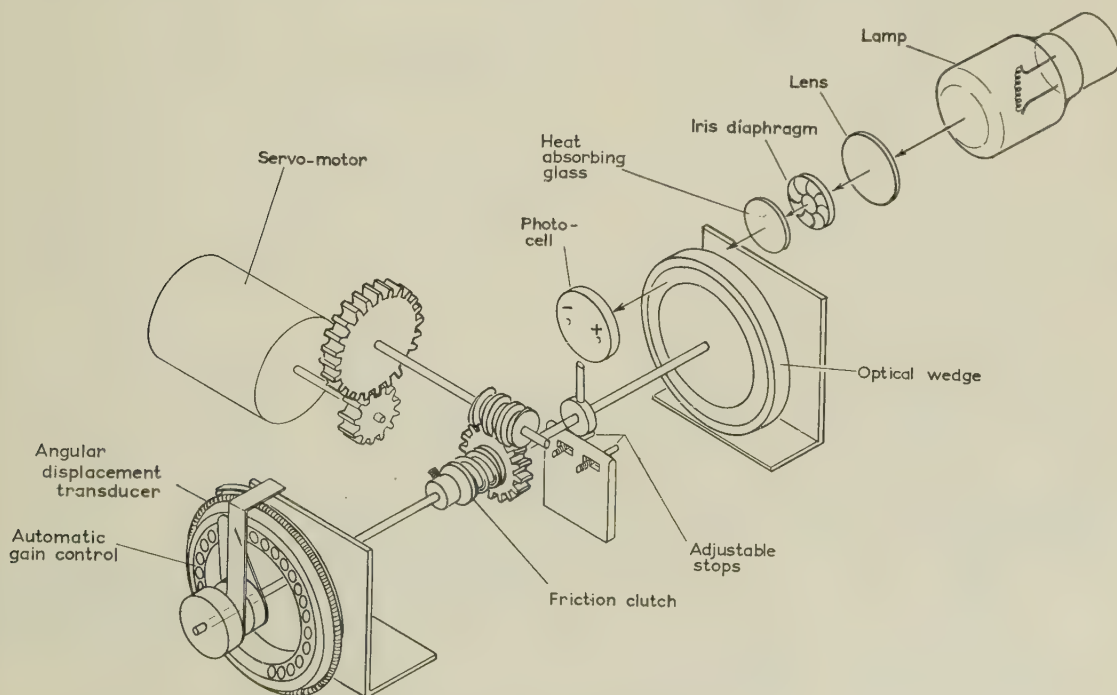


Fig. 1(b). Layout of servo-system.

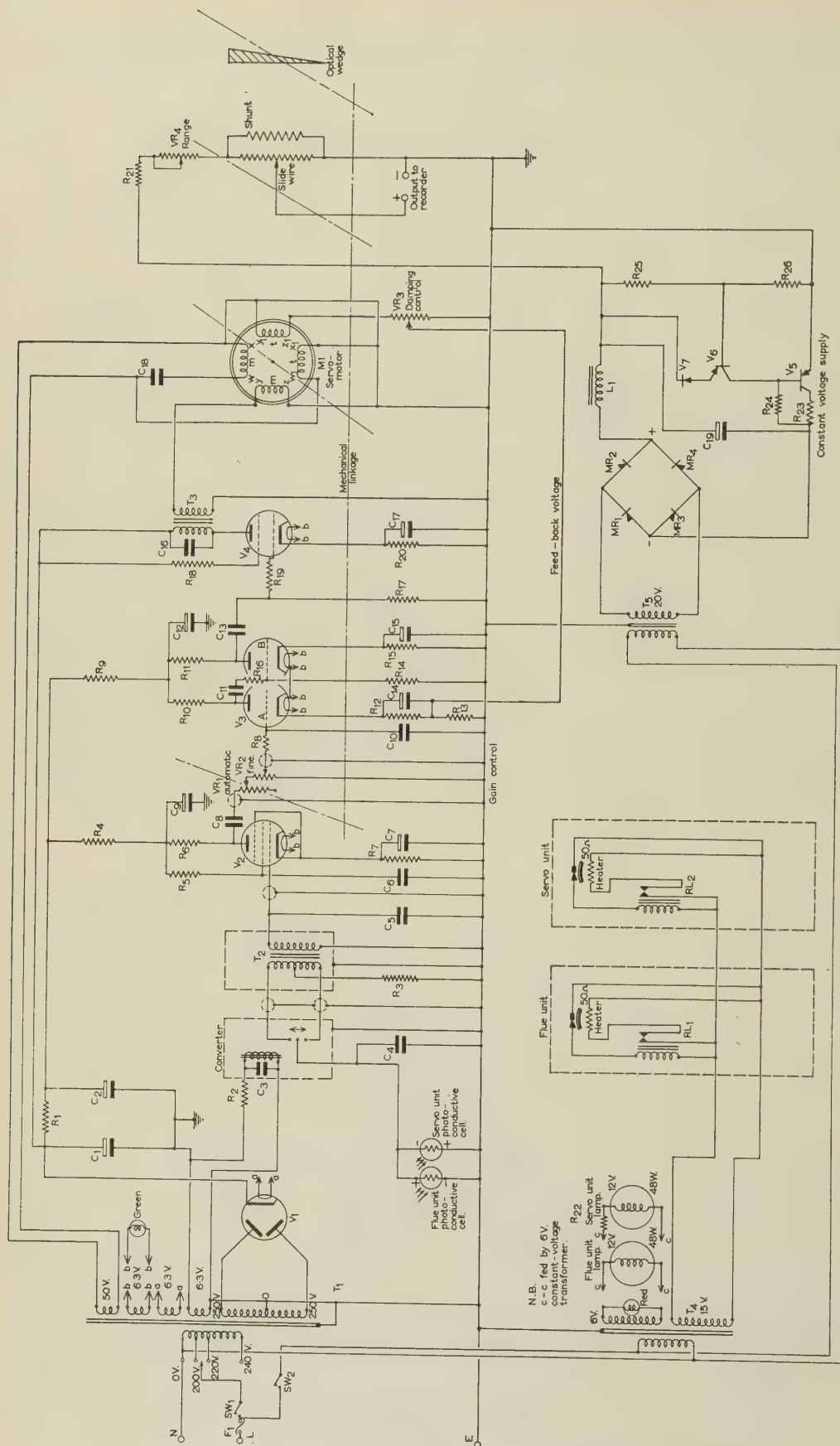


Fig. 2. Balancing and servo-unit.

- $R_1 = 22 \text{ k}\Omega$
 $R_2 = 650 \Omega$
 $R_3 = 500 \Omega$
 $R_4 = 47 \text{ k}\Omega$
 $R_5 = 1 \text{ M}\Omega$
 $R_6 = 330 \text{ k}\Omega$
 $R_7 = 4.7 \text{ k}\Omega$
 $R_8 = 220 \text{ k}\Omega$
 $R_9 = 220 \text{ k}\Omega$
 $R_{10} = 220 \text{ k}\Omega$
 $R_{11} = 220 \text{ k}\Omega$
 $R_{12} = 100 \Omega$
 $R_{13} = 1 \text{ M}\Omega$
 $R_{14} = 4.7 \text{ k}\Omega$
 $R_{15} = 10^5 \Omega$
 $R_{16} = 1 \text{ M}\Omega$
 $R_{17} = 1 \text{ M}\Omega$
 $R_{18} = 33 \text{ k}\Omega$
 $R_{19} = 100 \text{ k}\Omega$
 $R_{20} = 1 \text{ k}\Omega$
 $R_{21} = 2.2 \text{ k}\Omega$
 $R_{22} = \text{value depends on load resistance}$
 $R_{23} = 9 \Omega$
 $R_{24} = 150 \Omega$
 $R_{25} = 68 \Omega$
 $R_{26} = 2 \Omega$
 $R_{27} = 1 \text{ M}\Omega$
 $R_{28} = 5 \text{ k}\Omega$
 $R_{29} = 2 \text{ M}\Omega$
 $R_{30} = 10^5 \Omega$
 $C_1 = 1 \text{ M}\Omega$
 $C_2 = 16 \mu\text{F}$
 $C_3 = 0.2 \mu\text{F}$
 $C_4 = 2 \mu\text{F}$
 $C_5 = 0.01 \mu\text{F}$
 $C_6 = 50 \mu\text{F}$
 $C_7 = 0.1 \mu\text{F}$
 $C_8 = 8 \mu\text{F}$
 $C_9 = 0.002 \mu\text{F}$
 $C_{10} = 8 \mu\text{F}$
 $C_{11} = 0.1 \mu\text{F}$
 $C_{12} = 0.1 \mu\text{F}$
 $C_{13} = 0.1 \mu\text{F}$
 $C_{14} = 25 \mu\text{F}$
 $C_{15} = 25 \mu\text{F}$
 $C_{16} = 0.5 \mu\text{F}$
 $C_{17} = 50 \mu\text{F}$
 $C_{18} = 8 \mu\text{F}$
 $C_{19} = 1000 \mu\text{F}$
 $V_1 = 6\text{X5}$
 $V_2 = \text{EF37A}$
 $V_3 = 6\text{SL7}$
 $V_4 = 6\text{L6}$
 $V_5 = \text{V30-30P transistor}$
 $V_6 = \text{OC72 transistor}$
 $V_7 = \text{std } \times 3/7 \text{ silicon junction diode}$
 $MR_1 = \text{Partridge type DEF D678F}$
 $MR_2 = \text{Partridge type F1881}$
 $MR_3 = \text{Partridge type DEF D678F}$
 $MR_4 = \text{Partridge type DEF D678F}$
 $T_1 = \text{Secondaries } 6.3 \text{ v } 1.5 \text{ A, } 6.3 \text{ v } 2 \text{ A, } 6.3 \text{ v } 100 \text{ mA, } 50 \text{ v } 160 \text{ mA}$
 $T_2 = \text{Partridge type DEF D678F}$
 $T_3 = \text{Partridge type DEF D678F}$
 $T_4 = \text{Secondaries } 6 \text{ v } 1 \text{ A, } 15 \text{ v } 5 \text{ A}$
 $T_5 = \text{Secondaries } 20 \text{ v } 1 \text{ A}$
 $L_1 = 0.3 \text{ H}$
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 $L_{100} = 0.3 \text{ H}$

vided to enable the beam width to be varied. A series resistor is connected into the lamp supply circuit so as to adjust the effective lead resistance to be the same as that for the flue unit lamp supply, thereby ensuring that the filament temperatures will be the same in both cases. A quick change fitting is employed to attach the optical wedge to the unit; this enables an easy interchangeability of wedges, the one used being dependent on the maximum smoke density to be measured.

Amplifier unit

The amplifier (Fig. 2) is based on the design of the type used in the A.E.I. potentiometric recorder, since a number of these recorders are used in these laboratories and it was felt that the range of spares that need be kept in stock would be simplified. Any out-of-balance d.c. signal from the two photocells is converted to an a.c. signal by a Carpenter varized relay* and is fed, via transformer T_2 to valve V_2 , which together with valve V_3 forms a conventional R.C. coupled amplifier. The amplified signal from V_3 is passed to the power amplifier valve V_4 , the output from which is used to drive the servo-motor. The servo-motor, which incorporates a tacho-generator, is supplied with a 50 volt alternating supply from transformer T_1 . This supply is fed to the generator winding W_1X_1 , and through the 90° phase-changing capacitor C_{18} to the motor winding WX . The amplified out-of-balance signal from V_4 is fed to the motor winding YZ , the phase of this signal being such that the motor is caused to rotate in the appropriate direction. The generator output from winding Y_1 , Z_1 is injected via the balancing control VR_3 , into the cathode of V_3 .

Automatic gain control

The amount of light received by the photocell decreases arithmetically as the optical density increases, and the out-of-balance signal from the photocell falls off rapidly at the higher optical densities. Thus if the amplifier gain is adjusted to give optimum operation at low optical densities, the speed of response of the servo-system becomes too low at high densities. If, on the other hand, the gain is set so as to give optimum sensitivity at high optical densities, hunting of the servo-mechanism due to too great a sensitivity occurs at the low densities. It has, therefore, been found necessary to incorporate an automatic gain control VR_1 , which is mechanically coupled to the optical wedge. A wiper, which rotates with the wedge, makes contact with a series of studs constituting tappings along a resistance chain, the value of which has been found by experiment. This effects a gradual increase in gain as the input signal decreases.

Angular displacement transducer

This consists of a circular slide wire, the wiper arm of which is mechanically connected to the shaft driven by the servo-motor. The supply to the slide wire is obtained from a resistorized stabilized voltage circuit as described by Aspinall (1957), using a Zener silicon diode as a reference source. The output from the transducer, which is directly proportional to the angular rotation of the wiper arm and thus to that of the optical wedge, is fed to any suitable potentiometric recorder. The value of the voltage applied across the slide wire can be varied; thus a full-scale deflection can be obtained on the recorder for any optical density up to the maximum obtainable in the particular wedge in use.

3. Multi-channel switching unit

To enable the one amplifier and servo-unit to be used in conjunction with more than one flue unit, a selector switch device is synchronized with the recorder switching system, so as to connect each flue unit in turn to the amplifier.

It is necessary to switch only one connection to each flue unit, namely the positive side of the photocell, so that in effect only a single-pole multi-position switch is required. In an earlier system a rotary relay was used for this purpose, but it was found to be unsatisfactory because of the variable contact resistance of the sliding contacts.

The present system uses a bank of Post Office, type 3000 relays, which are actuated by a voltage impulse obtained from the recorder, coincident with the recorder's own switching from one channel to the next. This impulse is obtained by means of a micro-switch installed in the recorder in such a way that it is operated through a lever from a toothed wheel, which forms part of the switching mechanism of the recorder. Thus each time the recorder switches itself from one channel to another, the micro-switch is momentarily closed, and the external switching unit connects the next flue unit to the amplifier and servo-unit.

The circuit is shown in Fig. 3. The sequence is as follows:

- consider all relays to be de-energized. Flue unit 1 is connected to the amplifier unit through contacts $RL2c$;
- the micro-switch closes, energizing $RL1$. The resistor R_1 and capacitor C_1 serve to delay the breaking of contacts $RL1a$ for sufficient time to enable $RL2$ also to be energized through contacts $RL2a$. Flue unit 1 is thus disconnected from the amplifier and flue unit 2 is connected through contacts $RL3c$ and $RL2c$. When the micro-switch opens, relay $RL1$ is de-energized, but $RL2$ remains energized through contacts $RL2a$ and $RLNa$. The optical density meter now balances itself and the recorder prints the appropriate output voltage. The recorder then switches to the next channel;
- the micro-switch closes again. As before, $RL1$ is energized, but only after $RL3$ has been energized through contacts $RL1a$, $RL2b$ and $RL3a$. Flue unit 2 is thus disconnected, and flue unit 3 is connected through contacts $RL4c$, $RL3c$ and $RL2c$. When the micro-switch opens, $RL3$ remains closed through contacts $RL3a$ and $RLNa$;
- this sequence is repeated with every operation of the microswitch, each action closing another relay in the bank. Eventually the closing of relay $RL(N-1)$ switches flue unit $N-1$ to the amplifier, and finally;
- when RLN is energized, the supply to all the preceding relays (except $RL1$) is cut off by the opening of contacts $RLNa$, reconnecting flue unit 1 to the amplifier. The whole action is then repeated.

Normally the number of channels from the recorder to this switch $N-1$ will be the same as the number of channels on the recorder (i.e. for a 16-channel recorder 17 relays will switch 16 flue unit channels) in order to maintain synchronization between the flue units and recorder channels. However, several flue unit channels may be unused, and the corresponding recorder channels used for other purposes.

4. Performance

Calibrations are carried out in conjunction with an electronic multi-channel potentiometric recorder by placing neutral density filters in the light beam of a smoke-free unit.

* Telephone Manufacturing Co. Ltd.

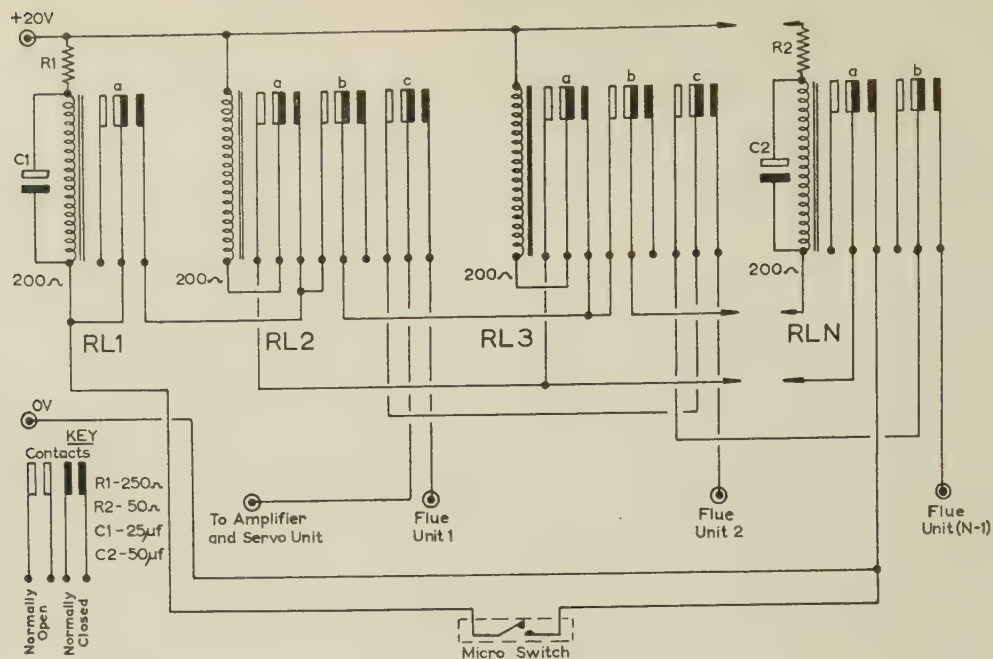


Fig. 3. Switching unit.

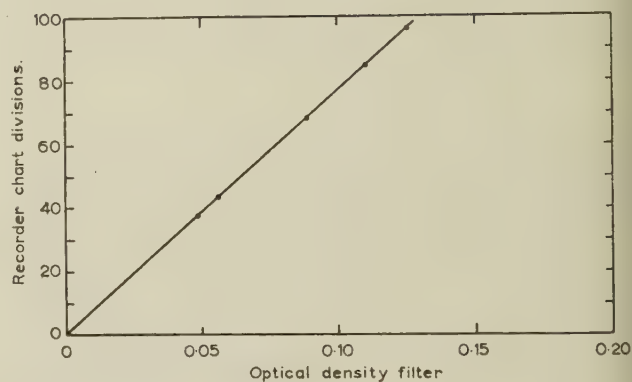
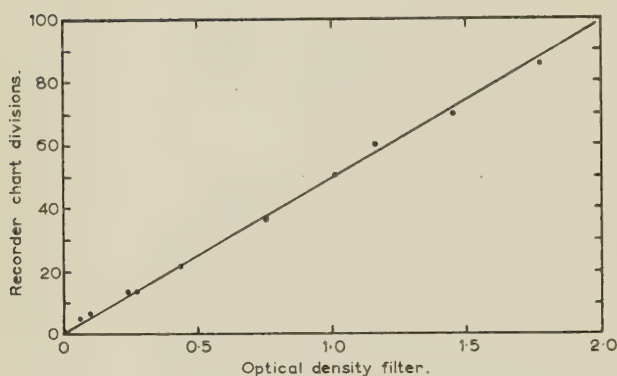


Fig. 4. Typical calibrations of recording optical density meter.

Fig. 4 shows the calibrations obtained using two optical wedges of nominal values of 0.0-0.1 and 0.2-2.0 optical density. It will be seen that the output varies linearly with optical density, over the range of the calibration.

Stability tests were made, over a period of several days, during which the laboratory temperature varied between 55 and 80° F and normal mains voltage fluctuations occurred. A nominal 0.0-0.1 optical density wedge was used and it was found that the random drift amounted to ± 0.0006 optical density unit, i.e. $\pm 0.6\%$ of full-scale deflection. With the use of the automatic gain control the speed of response of the recorder is constant and approximately one second for full travel of the wedge, even up to densities of 2.0 units.

5. Conclusions

The optical density meter described provides a reliable laboratory instrument for the measurement of smoke density. Its speed of response and high sensitivity allow full advantage

to be taken of the speed of electronic recorders. This enables rapid fluctuations in smoke emission to be followed in detail.

The flexibility of the design enables the densities of smoke emissions from several flue units, with the use of one servo-operated balancing system to be fed, with other data, to one multipoint recorder. The optical density meter has been used in the Domestic Appliance Laboratories of the British Coal Utilisation Research Association for over two years and has given reliable service.

Acknowledgments

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oxide resistor furnace for high-temperature operation

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Abstract

Thoria-base oxide resistor furnace has been constructed for operation at temperatures up to 2400° C in an oxidizing atmosphere. The maximum temperature attainable is limited by the ionization of the air in the vicinity of the oxide resistor, and simple means of overcoming this limitation are suggested. The furnace may prove attractive for some specialized investigations, where the requirement for an oxidizing atmosphere is sufficient to override the inherent fragile nature of the resistor element.

1. Introduction

THE conduction of electricity by some refractory metal oxides at elevated temperatures was used by Nernst and Wild (1900) in constructing a light source, whilst Gellener in 1905 has described an oxide resistor furnace. A completely successful furnace was not available, however, until Geller (1941, Lang and Geller 1951) constructed his multi-element furnaces in 1940. These furnaces consisted initially of thoria-base resistors in the form of rods, mounted vertically between zirconia-yttria contact blocks which were cemented platinum/rhodium lead wires. The contact blocks served the purpose of establishing continuity between the lead wires and the heating element and, because of their higher conductivity, provided a temperature gradient between the rods and the lead wires.

Electrical continuity between the thoria rods and the contact blocks was maintained by painting the rods and the contact blocks with finely ground material of their respective compositions, the rods merely resting in wide-angle conical recesses in the contact blocks. Irregularities in the area of contact were accommodated by the high electron emissivity of the oxides at elevated temperatures. Geller described the construction of furnaces of three and eight elements capable of giving a uniform hot zone at temperatures up to 2000° C, the elements being mounted vertically. At temperatures above 1850° C the elements tended to warp in use and this was attributed to impurities in the yttria.

The limitations of oxide resistors are the negative temperature coefficient of resistivity, 'channelling' of current on one side of the element or the centre of larger elements, thereby restricting their size, fragility and the difficulty of making end connections to metallic lead wires. The negative temperature coefficient introduces difficulties, since the furnace must be fitted with an auxiliary heater to raise the temperature to a temperature at which it conducts significantly. As temperature rises and the resistance of the oxide heating element decreases, with a constant applied voltage the element tends to become progressively hotter and eventually burns out. A solution is to provide a ballast resistance to limit the current and for small furnaces tungsten lamps can be selected to give a compensating positive coefficient of resistance. In spite of these limitations the oxide resistor

furnace does offer the possibility of a controlled high-temperature furnace capable of working in an oxidizing atmosphere. This makes it attractive for some ceramic studies where dissociation of oxides must be prevented, since most available furnaces operate in neutral or reducing atmospheres at temperatures above 1700° C.

2. Development of the oxide resistor furnace

Preliminary experiments were carried out using commercially available thoria tubes, since they are less likely than solid rods to deform under load at high temperatures for a given weight; also a small high-temperature zone inside the tubes appeared attractive, since a smaller power supply would be required for a given temperature. These experiments indicated the desirability for the following features to be incorporated in a successful furnace designed for temperatures above 2000° C: (a) the tubes should be of high density, free from open porosity to reduce the tendency to further sintering and deformation at temperatures above 1900° C; (b) contact blocks, as described by Geller, are essential to prevent volatilization of platinum lead wires; and (c) the thoria tubes should be of graded composition, the central portion being pure thoria and the ends thoria-yttria solid solutions of higher electrical conductivity to provide a thermal gradient between the central hot zone and the contact blocks. Whilst this restricts the size of the central zone it has the advantage of reducing the overall voltage considerably.

3. Construction and operation of the oxide resistor furnace

3.1 Preparation of the thoria tubes

Thoria tubes were slip cast in plaster moulds using a process which has been described in detail by Murray, Denton and Barnes (1956). Thoria bodies prepared in this way have a high density with very little open porosity. In order to impregnate the ends with yttria, tubes were obtained in the prefired state whilst still porous and dipped into a solution of yttrium nitrate ($Y(NO_3)_3 \cdot 6H_2O$, 10 g made up to 15 ml. with distilled water) to the desired height. The tubes were then drained dry and pulled, by means of a geared motor, through a horizontal tube furnace maintained at 1100° C. The furnace tube projected some 6 in. from each end of the casing and the thoria tubes could be drawn through the furnace without suffering from thermal shock.

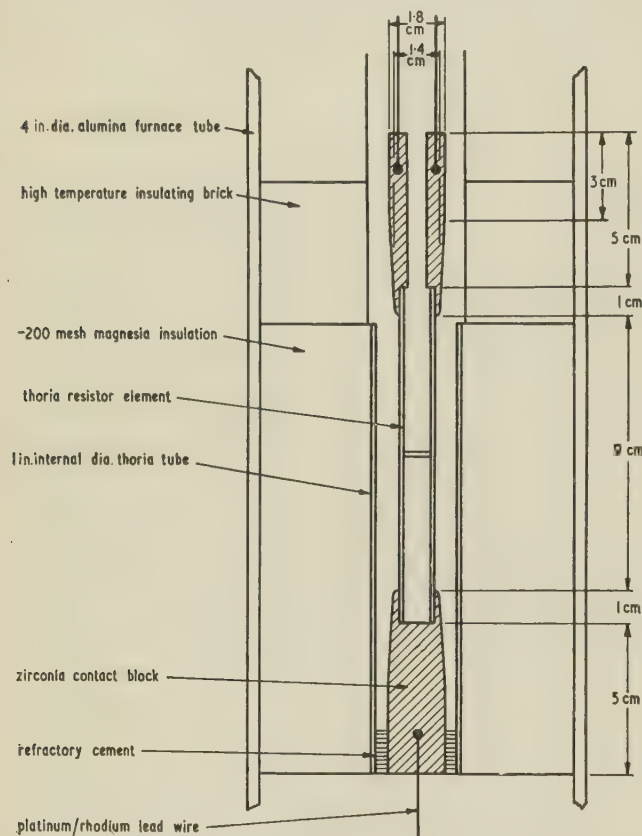
As a check on the quantity of yttria added, the tubes were weighed before and after each pass. Ideally it is desirable to obtain a continuous gradation from pure thoria in the central portion of the tube to a thoria-yttria solid solution at the ends which has an electrical resistivity/temperature characteristic similar to that of the zirconia contact blocks. An adequate approximation to these conditions was obtained

by dipping the tubes in yttrium nitrate solution to progressively greater depths.

When all the yttria had been added support plates of thoria cut from the ends of the tubes after slip casting were placed centrally in the tubes and cemented in position with thoria/hydrochloric acid wash. The thoria tubes were then sintered at 1675° c for 4 hours, final dimensions being 11 cm × 1 cm diameter and wall thickness of 1 mm to 1.5 mm.

3.2 Fabrication of contact blocks

Contact blocks were prepared from zirconia, stabilized with 5–6 wt. % CaO, by cold pressing using a Perspex binder and sintering at 1250° c. The blocks were then turned in a lathe to a shape and dimensions as given in the Figure. The taper assists in giving a temperature gradient down the



Section of oxide resistor furnace assembly.

contact blocks and so further reduces the gradient at the tube/contact block junction. Oversize holes to accommodate the ends of the thoria tubes and the platinum/rhodium lead wires were then drilled in the zirconia, and a sight hole in the upper block allowed for viewing the specimen and plate with an optical pyrometer. The 0.020 in. diameter Pt/13%Rh lead wires were heated in an oxy-coal gas flame until the ends were molten. The balled ends of the wires were then inserted into the contact blocks and a slurry of zirconia in hydrochloric acid run in until the holes were full of zirconia.

Sintering to 1450° c caused the zirconia contact blocks to shrink round the balls to give a tight grip, ensuring good electrical contacts. The holes in the blocks which receive the ends of the thoria tubes were then drilled out to give a slight clearance, the gaps being filled with a zirconia slurry after inserting the ends of the thoria tube, and the assembly finally

fired to 1650° c. This gave a reasonably tight grip between the tubes and the contact blocks, although this is not really essential to ensure electrical continuity owing to the high emissivity of the oxides used.

3.3 Assembly of the furnace

The supporting furnace was platinum-wound on an alumina tube, 12 in. long and 4 in. internal diameter, mounted vertically. Coaxial with this tube a thoria tube, 1 in. internal diameter, was cemented at the base, and the annulus between the tubes packed with powdered magnesia to provide thermal insulation between the two tubes. The complete thoria resistor assembly was then mounted centrally inside the thoria tube and the lower connection led out through the bottom of the furnace. This connection was made live with respect to earth since it was remote from the operating face of the furnace. High-temperature insulating bricks were then mounted above the assembly, which was positioned to give maximum separation from the thoria tube to reduce the risk of high-voltage flash-over.

Power for the furnace was derived from a Variac-fed transformer, the output of which could be switched remotely to give up to 500 v at 3 A or 1000 v at 1 A. Ballast resistors or electric light bulbs in the primary and secondary of the transformer could be switched in series/parallel to maintain constant power input to the furnace.

4. Operation

Owing to the thermal lag between the supporting furnace and the oxide resistor, it was necessary to allow some 6–8 hours for the resistor to attain a temperature at which it was sufficiently conducting to absorb significant power from the 1000 v supply. However, at temperatures above 1400° c the furnace was found to be flexible and was capable of being heated rapidly without failure of the assembly. The negative coefficient of resistivity of the oxide results in a progressive lower voltage and higher current being drawn as the temperature increases. A practicable heating cycle is as shown in the Table.

(1)	(2)	(3)	(4)	(5)	(6)
0	870	0	0	0	0
20	1130	1000	—	0.080	—
50	1155	1000	620	0.085	52.6
78	1325	900	620	0.21	130
81	1440	900	620	0.34	211
83	1500	900	570	0.36	205
92	1620	750	520	0.48	250
100	1615	690	495	0.46	228
113	1820	650	460	0.72	331
130	1840	650	435	0.76	330
144	1920	620	415	0.93	385
159	2000	580	405	1.12	454
182	2060	500	390	1.30	506
183	2100	500	340	1.90	645
200	2130	500	330	2.00	660
230	2300	500	320	2.50	800

(1) Time (min); (2) temperature (° c); (3) total voltage (v); (4) voltage across oxide resistor (v); (5) current (A); (6) power into resistor (w).

The maximum temperature attained in the furnace was approximately 2400° c, and was limited by conduction between the contact blocks and the outer thoria tube because of high emissivity of the oxides and the ease of ionization

air gap; in no case was there any warping of the thorium indicating that it would still operate at higher temperatures if the problem of arcing could be overcome.

The risk of arcing can be prevented by reducing the overall potential and/or providing better electrical insulation between contact blocks. Reduction of the applied potential can be accomplished by using a tube of larger wall thickness or larger external diameter. The figures for the temperature-voltage characteristics given above are not equilibrium values because there is a time delay in heating the magnesia, and a slightly improved performance might therefore be achieved at the expense of lower heating rates. A controlled small addition of yttria to the whole of the thorium tube would also result in lower voltages; data for the electrical conductivity of some compositions have been given by Hund and Mezger (1952). Electrical insulation may also be achieved by replacing the 1 in. thorium tube with magnesia, which is a better electrical insulator and has a sufficiently high melting point to be usable. Increasing the clearance between the resistor and this tube would also result in some improvements.

A life of more than 40 hours above 2000° C has been obtained from a thorium element without deformation, and it has been found that the life of an element was governed by mechanical shocks on inserting and removing it from the operating furnace. With care the risk of fracture is not considered to be excessive, since the elements are not very sensitive to shock except when the ends are of high yttria content. Above 8 wt. % yttria this was particularly pronounced, perhaps due to lack of homogeneity of the yttria-magnesia solid solutions.

The magnesia insulation was found to sinter rapidly and cracking was necessary after heating above 2000° C unless material of graded particle size was used, -200 + 250 mesh magnesia being satisfactory in reducing the tendency to crack and shrink away from the thorium tube. The graded material has an additional advantage of improved thermal

insulation at high temperatures, since radiation losses across adjacent particles are least in powders of uniform particle size (Kingery, Klein and McQuarrie 1958).

4. Conclusions

A simple high-temperature oxide resistor furnace has been developed capable of working in an oxidizing atmosphere up to 2400° C. Limitations of this furnace are the brittle nature of the refractory tubes, necessitating careful assembly, and the risk of arcing at high temperatures. These limitations should not prove insuperable for some specialized applications where an oxidizing atmosphere is essential; with the proposed modifications the limiting operating temperature may be determined mainly by the creep of the thorium or thorium-yttria resistors at temperatures above 2400° C.

Acknowledgment

Thanks are due to Mr. I. Denton of Metallurgy Division, Atomic Energy Research Establishment, Harwell, for his kind assistance in the slip-casting and initial firing of the thorium tubes used in this work.

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Method of modulating a high-intensity searchlight

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MS. received 17th October 1960, in revised form 19th December 1960

Abstract

A rotating shutter was designed in order to modulate the beam from a large military searchlight at 5–10 c/s. Its construction is described, with notes on the modulated waveform produced.

1. Introduction

THE searchlight described below was designed as a means of measuring the density of the atmosphere at heights between 30 km and 60 km, i.e. above the limit of normal radio-sonde measurements. The method was to direct a powerful searchlight beam upwards and measure the light scattered from it at various heights, by means of a photomultiplier. (The measuring station is 46 km from the searchlight, to eliminate multiply scattered light in the lower atmosphere.)

This method can only be used on cloudless nights, and even on moonless nights the light from the sky is greater than the scattered light to be measured by a factor of about 10^5 . Thus the searchlight beam must be modulated (i.e. interrupted a fixed number of times per second) so that its light can be distinguished from the steady sky light, and amplified by a.c. means.

The most powerful searchlight available was a military type with mirror 156 cm diameter using a 22 kw carbon arc lamp. The only method known to have been used previously to modulate such a searchlight (Elterman 1954) was a shutter of the venetian blind type. As shown in Fig. 1 this consists

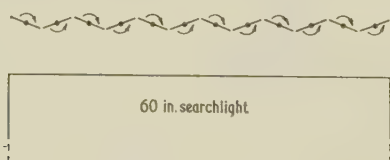


Fig. 1. 'Venetian blind' type of shutter, as used by Elterman.

of a number of rotating metal strips mounted in front of the searchlight barrel. It is somewhat unwieldy in this large size, and also gives rather a poor waveform. In Fig. 2(a) the full line shows the time variation of the searchlight intensity and the dotted line the first Fourier component, which has an amplitude only about 81% of the full searchlight intensity.

2. Design of a new shutter

A different type of shutter was designed, the aim being to produce the most intense modulated beam with a shutter compact enough to fit inside the existing searchlight barrel. The intensity of the modulated beam is greatest if the shutter

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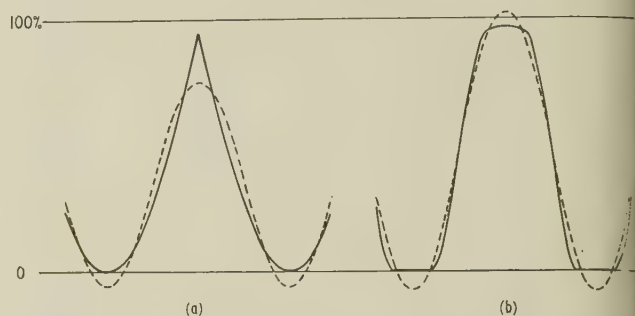


Fig. 2. Modulation waveform produced by two types of shutter (full lines). The dotted lines are the first Fourier components of each waveform. The level marked 100% represents the searchlight intensity without the shutter fitted. (a) Venetian blind type. (b) Semi-conical type.

produces an approximately square waveform (giving a high first Fourier component) and if the obstruction of the beam caused by the shutter (when fully open) is kept to a minimum.

These requirements were met by a shutter in the shape of half a hollow cone of semi-vertical angle 40° rotating about its axis which is at 50° to the axis of the searchlight barrel (see Fig. 3). At one part of its revolution the shutter comes between the arc lamp and the mirror, and cuts off the beam. Later in its rotation, when it allows light to reach the mirror, the shutter's position is as nearly as possible parallel to the searchlight beam, so causing minimum obstruction (Fig. 4(b)).

Possible difficulties with this type of shutter were expected to be: (a) excessive heating of the shutter by the arc; (b) arcing currents due to the shutter causing erratic arc behaviour; (c) difficulty in balancing the shutter dynamically. The first two difficulties were met by making the distance between arc and shutter six inches, despite a reduction in shutter size that a smaller gap would have allowed. The second two were minimized by choosing a fairly low rate of rotation of the shutter ($5\frac{1}{2}$ rev/s).

3. Construction of the shutter

Details of construction are shown in Fig. 3, where the arc is at A. The conical part of the shutter B is made of stainless steel sheet 0.028 in. thick, fixed along its straight edges to two lengths of steel angle C. These latter are fixed to a framework containing two ball races which revolve on a length of 1 in. steel rod D fixed to the searchlight barrel. The outer edge of the shutter is fixed to a circular steel frame E which (being 88 cm in diameter) is most conveniently made from a number of curved strips bolted together. A complete ring is used to counterbalance the weight of the shutter, extra strips F being used opposite the shutter to make up the required weight. A counterweight in this position does not cut off light by coming between the arc and the mirror.

for dynamical balance a second counterweight G is added. This does come between arc and mirror, but is so positioned that its shadow on the mirror comes largely on

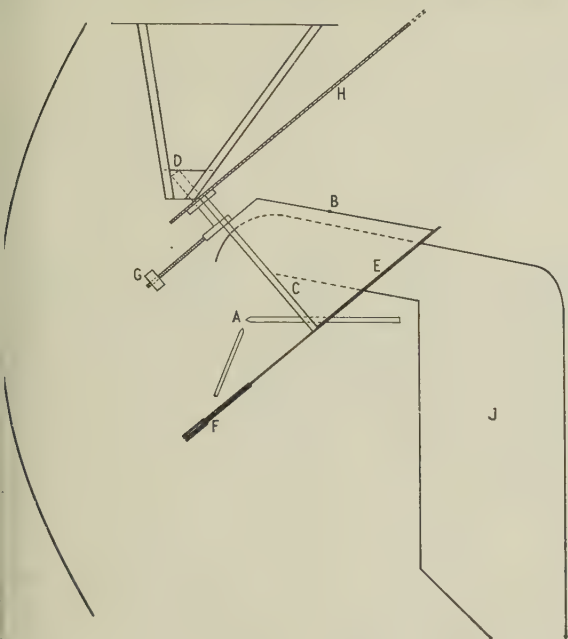


Fig. 3. Construction of the semi-conical shutter (shown in the 'open' position).

part from which the beam is in any case obscured by the shutter.

The shutter is driven by a $\frac{1}{2}$ h.p. squirrel cage electric motor, through a sprocket chain H, lubrication of the chain drive and shutter bearings being by colloidal graphite. The motor switch is coupled with the main arc switch so that the arc cannot be switched on with the shutter stationary (this would be the shutter if in the 'closed' position). Also, to minimize strain in the drive, reduced power is applied to the motor the first ten seconds after switching on.

The only modification needed to the searchlight was to remove the extractor fan and duct J from the top of the barrel to the bottom—with the incidental advantage that the duct now is in line with the lamp, and their obstruction thereby removed.

4. Performance

The shutter has given entirely satisfactory service, apparently without affecting the operation of the arc lamp. The size of the counterweights was fixed initially by calculation, but needed no subsequent adjustment as there was no appreciable vibration when running at $5\frac{1}{2}$ rev/s. The speed of rotation is constant to about 1% (as the driving motor, though not of a synchronous type, is only lightly loaded). This constancy is adequate in view of the

use of a phase-sensitive detector in the photomultiplier amplifier.

The waveform of the modulated beam is shown in Fig. 2(b) (full line), its first Fourier component (dotted line) having an amplitude 110% of the unmodulated beam intensity.

The obscuration of the beam before and after conversion

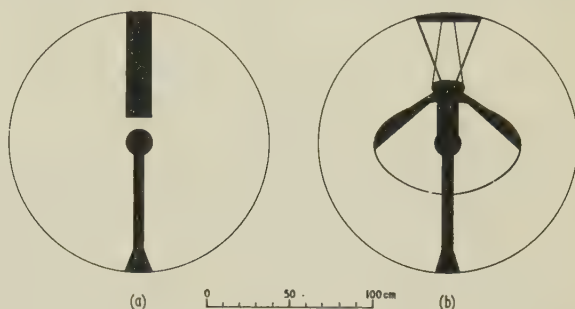


Fig. 4. Front view of searchlight showing fraction of the beam obscured (a) before conversion, (b) after addition of shutter and change in ventilation duct.

(as shown in Fig. 4) is as follows, expressed as a percentage of the mirror area:

Before conversion:

arc lamp	2.4%
extractor duct	4.6%
total	7.0%

After conversion:

extractor duct (includes lamp)	3.9%
shutter (including counterweights)	4.2%
shutter support and drive	3.2%
total	11.3%

The only future modification envisaged is a possible increase in the modulation frequency if this should be found desirable. The frequency could probably be raised to 10 c/s by very careful balancing of the shutter. A further increase would be possible if the shutter size was reduced, but this would mean bringing it nearer the arc lamp and the feasibility of this would need careful testing.

Acknowledgment

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Indium resistance thermometers

by B. YATES, Ph.D., A.Inst.P., and C. H. PANTER, B.Sc., Physics Department, Bradford Institute of Technology, Bradford

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Abstract

A description is given of the construction of an indium resistance thermometer, which is particularly suitable for use in cryostats where working space is limited. The ice point resistance of the thermometer changed by less than five parts in 30000 after repeated cooling to 14° K. Mathematical representations of the variation of resistance with temperature are given for the greater part of the temperature range 14 to 323° K.

1. Introduction

INTEREST has recently been expressed in the possibility of using indium as a resistance thermometer material at low temperatures. Attention has been drawn to its comparatively high temperature coefficient of resistance below room temperature by Barber (1960), though accounts of its suitability as a thermometer are limited. White and Woods (1957) and White, Woods and Anglin (1958) have reported favourably on the reproducibility of calibration curves for 99.999% pure indium wire (Tadanac brand produced by the Consolidated Mining and Smelting Company of Canada, Ltd.), in the temperature range 3.4 to 300° K, and this report led the authors to construct a thermometer from spectrographically standardized indium wire, containing impurities to less than 6 p.p.m., obtained from Johnson Matthey and Co. Ltd.

2. Experimental

The mounting of the thermometer is shown in Fig. 1. A basket of brass wire B had strips of mica M attached to its

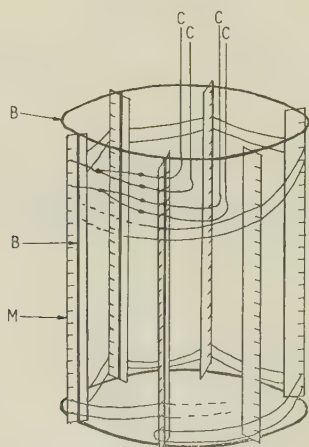


Fig. 1. Thermometer assembly.

B, wire basket; M, slotted mica strips; C, copper leads.

vertical members by Araldite. Indium wire, of diameter 0.010 in. was wound non-inductively and loosely between slots cut in the mica strips. No steps were taken to anneal the wire, since indium self-anneals at room temperature. In order to avoid the introduction of impurities into the thermometer, the ends of the wire were melted to short lengths of indium wire to form Y-junctions. These, in turn, were melted to 40 s.w.g. copper leads C. The whole arrangement was about 3.5 cm wide and 4 cm high. This design was adopted in order to leave the central region clear for the authors' particular experimental requirements. The thermometer was situated in a specimen chamber, which was suspended from the top of a second chamber. This chamber was normally surrounded by a Dewar vessel.

The thermometer was calibrated against the vapour pressures of liquid hydrogen, nitrogen and ethylene, at the sublimation point of carbon dioxide, the ice point and temperatures up to 323° K, obtained by using constant temperature water baths. A vapour pressure bulb, attached to the specimen chamber, was used at the lower temperatures and thermal equilibrium between the thermometer and its surroundings was established by means of exchange gas between the two chambers. Resistance measurements were made potentiometrically, and a constant current of 10 ma was employed throughout the calibration.

3. Results

Because of the method of calibration adopted it was necessary to interpolate over ranges of the characteristics in attempting to produce an acceptable mathematical representation. The result of this was as follows. Between 323 and 273° K the characteristic was linear, yielding a value of $(1/R_0)(dR/dT)$ of 0.00482 per deg (R being the resistance at absolute temperature T , and R_0 being the ice point resistance). Between 273 and 120° K the results were fitted to the quartic equation:

$$\begin{aligned} R/R_0 = & -4.5468 \times 10^{-2} + 3.33470 \times 10^{-3}T \\ & -7.0822 \times 10^{-7}T^2 + 1.2871 \times 10^{-8}T^3 \\ & -1.3459 \times 10^{-11}T^4 \end{aligned}$$

Between 120 and 40° K a straight line was used, yielding a value of $(1/R_0)(dR/dT)$ of 0.00350 per deg, whilst the curve through the hydrogen results met this line as a smooth continuation at 40° K. It may be added at this point that the scatter in the experimental points about the smooth curve in the region 14–20° K in no case exceeded 0.05° (14 results obtained in 4 runs extending over 3 months), whilst in the range 64–77° K the scatter in no case exceeded 0.2° (6 results obtained in 8 runs extending over 6 months). Near the other end of the scale, the overall variation incurred in the predicted ice point temperature between successive

to low temperatures amounted to 0.03° (6 measurements extending over a period of 5 months). The results of White *et al.* and those of Swenson (1955), obtained using indium supplied by A. D. Mackay, Inc., were found to agree with the present results at the ice point. The three sets of results were compared over the range 273°K . The highest value of $(1/R_0)(dR/dT)$ obtained by White *et al.* was 0.00471 per deg and occurred at 267.5°K . It agreed reasonably well with the present high temperature value, but their results indicate a change of sign of the temperature of their characteristic in the range 267.5 to 250°K . The present results and those of White *et al.* are in substantial agreement between 267 and 120°K , but commenced to diverge at about 120°K . The straight line through the present nitrogen calibration points ran only parallel to that of White *et al.* between about 100°K and 40°K ; the present resistance values being higher by about 1% at 77°K . The curves continued to run roughly parallel down to 14°K . Swenson's value of 0.00443 per deg $(1/R_0)(dR/dT)$ in the range 210 to 273°K was appreciably less than the other values reported, and his resistances

were somewhat higher than both previously mentioned sets of results over most of the range 273 to 63°K . At about 63°K his curve crossed the authors' and joined that of White *et al.* at about 40°K . These divergences are summarized in Fig. 2, in which ΔR is the difference between the authors' resistances and those of the other workers named, after their resistances had been reduced to agree with the present one at the ice point.

4. Conclusions

Three points of particular interest have emerged from this work. A variation of the conventional mica cross for supporting thermometer wire in a strain-free manner, which is more suitable for many applications, has been described. The low-temperature calibration has been derived after repeated cycling between room temperature and low temperatures, over a considerable period, during which the ice point resistance did not change by more than $0.0005\ \Omega$ in $3.4275\ \Omega$. The divergences between the three sets of results described draws attention to the danger in assuming that the crystalline form and impurity content of specimens drawn from different sources are sufficiently similar to render the individual calibration of indium resistance thermometers unnecessary, where high precision temperature measurement is required.

Acknowledgments

The authors wish to express their gratitude to Dr. F. E. Hoare, of the University of Leeds, for valuable practical forms of assistance, and to Dr. G. K. White, of the National Research Council, Canada, for supplying tabulated results of the work of White, Woods and Anglin.

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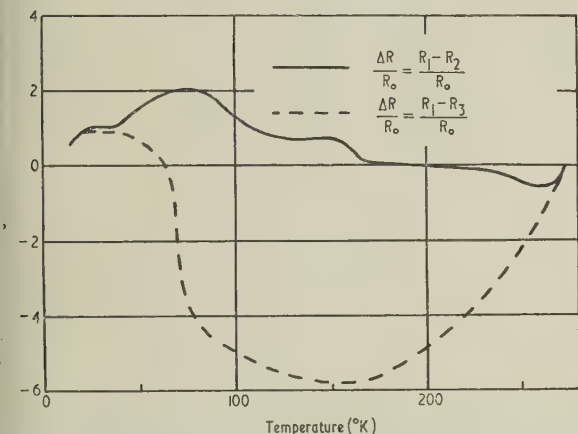


Fig. 2. Divergences in the observed temperature variation of the resistances of different specimens of indium.

R_0 , common ice point resistance; R_1 , authors' resistance at temperature T ; R_2 , reduced resistance of White *et al.* at temperature T ; R_3 , reduced resistance of Swenson at temperature T .

Vacuum radiation furnace with precise control of temperature gradients for crystal growth by sublimation

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MS. received 28th November 1960

Abstract

The furnace was designed for the growth of lead selenide single crystals at 775° C. It provides an inherently high degree of temperature uniformity and, without the use of a servo control system, the gradients can be adjusted and maintained to less than $\frac{1}{10}$ deg C/cm and $\frac{1}{2}$ deg C in 10 cm. A changed gradient can be established in 5 minutes. In heating from cold a steady temperature is attained in 75 minutes, and the furnace can be cooled in a few minutes. This performance is achieved by minimizing the total mass of heated material, and by the use of highly reflecting water-cooled silvered surfaces for the walls. An outline is given of the regulating system for controlling the absolute temperature to 0.1 deg C. Evaporation of the alloy heater element limits the maximum temperature to about 940° C, but this should be raised by the use of other elements.

1. Introduction

IN developing a method for the growth of single crystals of lead selenide by a sublimation process, the author (1961) found that very close control of temperature gradients was necessary in order to achieve crystals of useful size. Operating temperatures between 700° C and 850° C were used, and control of the gradient to better than $\frac{1}{10}$ deg C/cm and about $\frac{1}{2}$ deg C over a distance of 10 cm seemed desirable. Achievement of such detailed control with a conventional tube furnace would probably involve a very elaborate system of winding and electronic control; furthermore, because of the mass of the lagging material such furnaces usually have undesirably long response times, making them unsuitable when rapid changes of gradient are needed. The vacuum radiation furnace described in this paper was designed to avoid such limitations. The main characteristics aimed at were an inherently high degree of temperature uniformity, rapid and flexible detailed control of gradients to close limits, short heating and cooling times and the avoidance of the necessity for electronic control except for the absolute temperature, which could be monitored at a single point.

2. Outline of design

The general arrangement is shown in Figs 1 and 2. The basic object is to obtain an evacuated region containing a highly uniform density of radiation with a minimum mass of heated material. Thermal insulation for the walls is dispensed with and replaced by water-cooled highly reflecting silvered surfaces. In addition to preventing energy loss, the reflecting walls serve to improve the uniformity of the radiant energy density, since on the average the radiation is reflected

some 35 times before being absorbed. The energy input is well distributed close to the walls by the use of special formers.

With this arrangement the temperature gradients in the central region of the furnace do not exceed about $\frac{1}{10}$ deg C/cm. Final detailed control of the gradients around the crucible is achieved by means of a multi-tapped heater winding on an inner furnace. The gradients in the inner furnace are measured by a system of multiple differential thermocouples. To avoid the presence of further heated material in the furnace, and possible difficulties due to thermal deformation, the main support for the internal parts of the furnace is in the form of a water-cooled silver-plated steel tube.

3. Detailed description

The vacuum chamber comprises a cylindrical can bolted to a heavy brass back-plate, with a neoprene O-ring forming a vacuum seal. The can may be withdrawn on rails. The hot region of the furnace is bounded by the end and cylindrical walls of the can, and a split circular plate 7 in. from the back-plate. The split plate is cooled by contact with its supports and screens the back-plate through which all the tubes, supports and leads are sealed by neoprene gaskets. The main distributed heater is made in two easily removed sections, each consisting of a translucent silica former (manufactured by The Thermal Syndicate Ltd.) threaded with 0.025 in. $\times$ 0.1 in. Kanthal A tape (Kanthal, Hallstahammar, Sweden). The terminations are clamped to copper contact pillars on the back-plate, and the sections are here connected in series to give a total resistance of 20 ohms.

The inner furnace is constructed of pyrophyllite in three sections. The central tubular section has a helical groove for the winding, and internal slots to take tongues to secure the end sections. One end section has a snout for the capillary heater (Prior 1961) and both have spiral grooves for the winding. To reduce the occurrence of temperature gradients when the furnace is heated or cooled the effective wall thicknesses of the three sections are made equal. The winding is continuous over the three sections but is tapped at six points. The seven sections of the winding can be separately energized from the secondaries of seven transformers, each individually controlled with a Variac on the primary. Interaction through the voltage drop in the common connections is minimized by the use of heavy connections from the tapping points. This system, rather than seven independent windings, was used to simplify the winding and reduce the number of leads.

The multiple thermocouple assembly for measuring the temperature differences is shown in Figs 3 and 4. Platinum-1% rhodium/platinum-13% rhodium couples are employed,

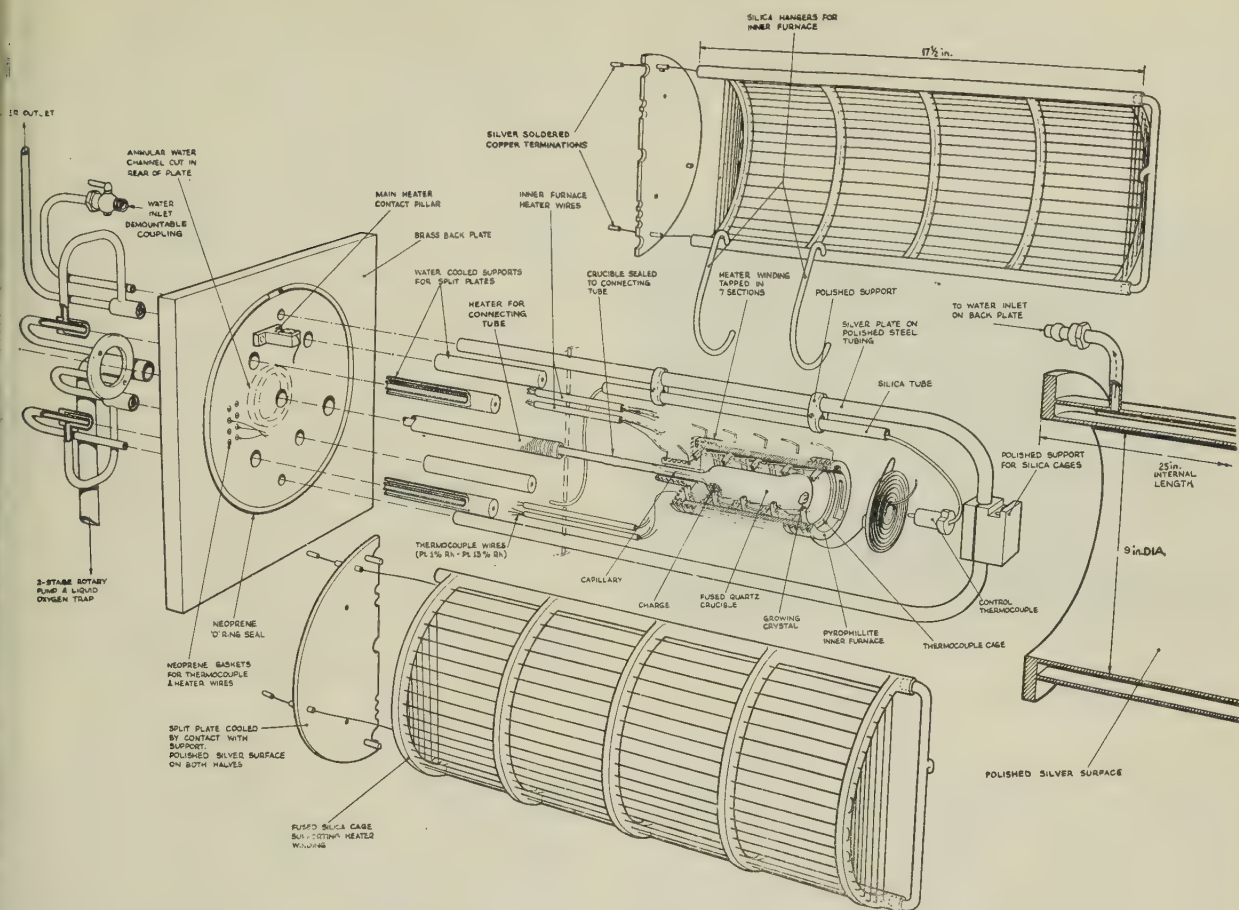


Fig. 1. Exploded diagram of furnace.

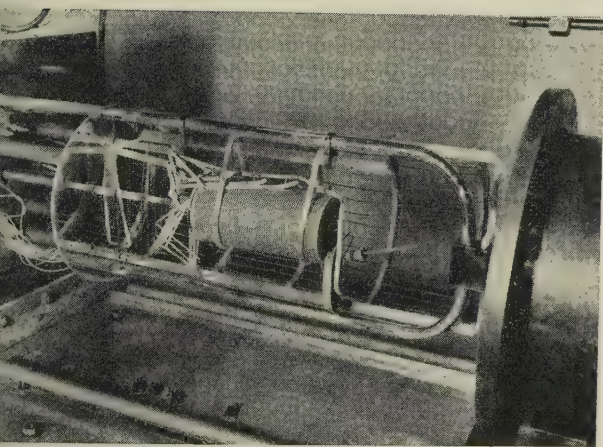


Fig. 2. Photograph of the furnace with one section of the main heater removed, and the inner furnace opened.

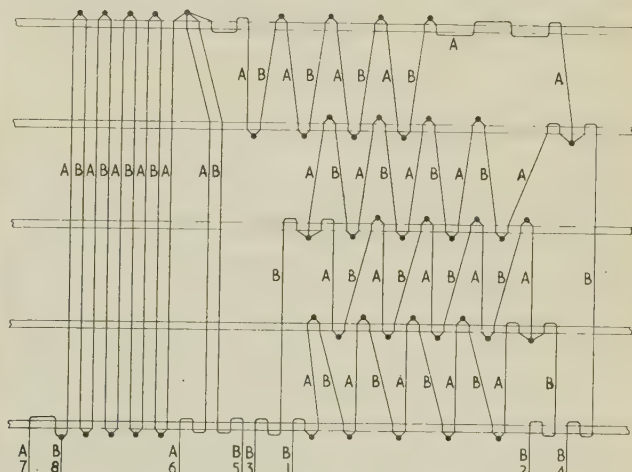


Fig. 3. Schematic diagram of the thermocouple assembly.
A, platinum-1 % rhodium; B, platinum-13 % rhodium.

wing Metcalfe (1950), with a view to long-term stability
e face of possible contamination when used unprotected
cuo. To avoid the possibility of spurious e.m.f.s. being
rated at any discontinuity of the wires, these are taken
tly through special neoprene seals (Prior 1958) in the
-plate, and then to a constant temperature enclosure
at 40° c, where connection is made to copper wires.
use of a five-fold differential system for measuring the

differences both increases the ease of measuring the small
potential differences, and also reduces the effect of spurious
e.m.f.s., due to strain or other inhomogeneities in the wire,
which can occur where a wire passes through a temperature
gradient.

By measuring the potential differences generated between
various pairs of the eight output wires, the temperature at
each end and the longitudinal gradients can be deduced with

some measure of self-checking. The differences measured between wires 5 and 1 were found usually to be some 40% less than those measured between wires 5 and 8; this is presumably because the equalizing effect of thermal conduction along the wires is appreciable and is greatest over the short sections. By consideration of internal checks of this

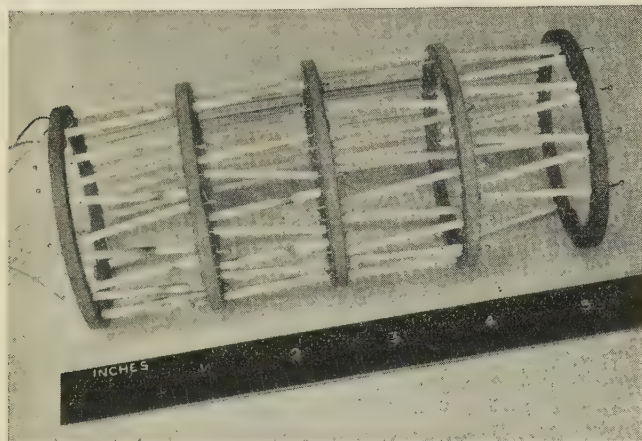


Fig. 4. Photograph of the thermocouple assembly. The rings are pyrophyllite and the spacers alumina.

sort the accuracy to which the temperature distribution can be deduced is about 0.1 deg C/cm at each point and about $\frac{1}{4} \text{ deg C}$ between the ends, for total temperature differences of a few degrees.

The vacuum system comprises a two-stage rotary pump and liquid nitrogen trap; the latter is necessary to prevent a deposit forming on the silvered surfaces as a result of thermal decomposition of the oil vapour. The pressure is monitored with a Tesla coil on the glass pumping connection and, provided that only a faint glow is obtained, the operation of the furnace is found to be satisfactory. The crucible is pumped with a separate system (Prior 1961).

4. Operation and performance

The furnace has the desired performance and has proved to be reliable and easy to operate. The fact that the thermal losses are almost entirely radiative and hence approximate to a T^4 law has several desirable consequences. In heating the losses are initially small and only rise rapidly as the operating temperature is approached; this, together with the small mass of material to be heated, leads to rapid attainment of stable conditions. A stable temperature around 775°C can be reached from cold with constant power input in about 75 minutes. The furnace can be cooled in a few minutes if required by breaking the vacuum and removing the can. As a result of the T^4 law, the temperature varies only as the square root of the supply voltage.

Rather less than 1 kw is needed for operation at 775°C , and from this a figure of over 97% for the mean reflectivity of the walls and other cooled surfaces can be deduced. In use gradual deterioration of the reflectivity occurs, but in continuous operation with two three-day runs per week it has been found sufficient to spend a few minutes once or twice a month in repolishing the surfaces. While a slight visible tarnish appears to have relatively little effect, initial smoothness of the surface was found to be very important, and prolonged polishing was required both before and after

the final silver plating. Initially, polished copper surfaces were used, but the power input required was significantly greater and tarnishing was much more rapid.

The highest temperature used was about 940°C , at which the performance was satisfactory except that the reflectivity fell more quickly. The limit of the present design is set by evaporation of the Kanthal heater tape and a consequent reduction in wall reflectivity. A slightly higher temperature could probably be reached by increasing the total area of the heater tape and so reducing the surface temperature required. A molybdenum element would probably enable substantially higher temperature operation, but an improved vacuum system would be necessary.

The degree of control of the gradients in the inner furnace is limited primarily by the accuracy and interpretation of the readings from the thermocouple system already described. The gradients with any particular distribution of currents in the seven sections of the heater were found to be fairly accurately additive functions of the gradients due to each section separately, so that after an initial calibration of the effect of each section the current distribution necessary for any desired temperature distribution could be derived on paper. The settling time for a change of gradient is about 5 minutes, though if the change involves a substantial change in total power input, the absolute temperature takes up to about 15 minutes to settle.

5. Absolute temperature control

Provided that variations of the order of $\pm 5 \text{ deg C}$ in the absolute temperature can be tolerated, it is sufficient to use a power supply with voltage regulation to $\pm 1\%$ and to make slight manual adjustments at the beginning of each run, or every few days, to compensate for changes in reflectivity. For some aspects of the crystal growing programme, however, control to limits at least equal to the fundamental reproducibility of the thermocouple was desirable and a regulating system was designed for a tolerance better than $\pm 0.1 \text{ deg C}$.

The object was to regulate the power in the main outer heater to maintain a constant output from the control thermocouple in the inner furnace. Since the inner furnace represents a thermal capacity in between the heater and the thermocouple, the lag in response is somewhat complex and necessitated careful design of the lag compensation circuit to achieve stable operation. Analysis of the phase and amplitude frequency response of the furnace indicated two principle simple lags of 600 and 60 second time constant, and these are compensated by a 600 second integrator and 60 second phase advance circuit.

The thermocouple output is backed-off against a stable voltage source, which is periodically reset against a standard cell. The error signal is amplified by a chopper amplifier operating at 40 c/s to avoid possible interference from the 50 c/s heater supply. After processing through the integrator and phase advance circuits, the signal is used to vary the on-off ratio of a rectangular wave of period about 6 seconds. The resulting proportional on-off signal is used to switch the power input to the furnace between a higher and a lower level. To widen the range of control the proportional on-off signal is taken to a reversible d.c. motor which drives a Variac through a reduction gear. In this way, after a period of asymmetrical working, the proportional on-off signal is restored to equal on and off periods, the Variac having been turned by the d.c. motor until the required mean power level is half-way between the higher and lower levels of the rapid

control system. The rate of this second integrator is so slow that it has no effect on the stability of the control loop, and the small and continuous motion of the d.c. motor is lost in the backlash of the reduction gear and does not reach the Variac.

Acknowledgments

The author is greatly indebted to Messrs. D. G. Coates and J. D. R. McQuillin for general assistance in assembly

and commissioning of the furnace, and to Mr. E. F. Good for the electronic design of the control system. This paper is published by permission of the Controller, H.M. Stationery Office.

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Notes and Comments

Noise in Electronic Devices

In October 1959 the Electronics Group held a short conference on 'Noise in Electronic Devices'. The seven papers there presented have now been published by Chapman and Hall Ltd., on behalf of the Institute and Society. The retail price is 35s. Members, Students and subscribers may obtain one copy each, for their personal use, at the reduced price of 24s. Their orders, with remittances, should be sent to The Institute of Physics and The Physical Society, 47 Belgrave Square, London, S.W.1.

Electron Microscopy Group Annual Conference 1961

The Electron Microscopy Group of the Institute and Society announces that its Annual Conference will be held from Monday, 10th July to Friday, 14th July 1961 at the University of Nottingham. The Conference will be concerned mainly with the physics of the electron microscope and its applications.

The following main topics will be discussed: Electron microscopes and electron optics—past, present and future trends, microscopy devices and attachments; Electron microscopy of thin films—including carbon, metal films, metal physics, magnetic domain theory, etc.; The theory and scope of electron diffraction methods; Miscellaneous techniques and applications of electron microscopy.

The proceedings on Friday 14th July will take the form of a symposium jointly with other interested bodies on 'The physics of sectioning and the embedding process'. It is intended that it should concern the mechanism of sectioning, with studies on the action of glass and diamond knives. Papers on embedding materials and methods and on their behaviour in the electron beam are also to be included. If

time permits, some papers on staining (specificity, electron scattering power) may also be included.

It is not intended that this symposium be used for reporting the results of application of these techniques, except in so far as they serve to illustrate the principles of ultra-microtomy.

Limited accommodation will be available in a University Hall of Residence. Registration is necessary and further information and application forms are available from the Administration Assistant, The Institute of Physics and The Physical Society, 47 Belgrave Square, London, S.W.1.

Modern developments in heat transfer

The University of Minnesota announces a second summer course in Modern developments in heat transfer, to be held at the University of Minnesota, Duluth, from 14th to 22nd August 1961. The first special course was presented by the University in 1958. The object of this second course is to provide a clear, basic exposition of the fundamental physical mechanisms underlying the various heat and mass transfer processes as some of the recent developments in the field are explored.

A preliminary outline of the programme is as follows: General review and exposition of the current status and problems in heat and mass transfer; Inter-relations between heat, momentum and mass transfer; Radiation; Plasma physics; Heat transfer with phase change (boiling and condensation); Mass transfer cooling; High-speed heat transfer; Properties for heat transfer calculations; Numerical methods in heat transfer.

The course will be directed by Dr. E. R. G. Eckert, Professor of Mechanical Engineering, Director of the Heat Transfer Laboratory, University of Minnesota. Further information may be obtained from the Director, Center for Continuation Study, University of Minnesota, Minneapolis 14.

Photoelectric optical pyrometer

by J. MIDDLEHURST, M.Sc., A.Inst.P., and T. P. JONES, M.Sc., Grad.Inst.P., Division of Physics, C.S.I.R.O., Sydney, Australia

MS. received 3rd October 1960

Abstract

An optical pyrometer is described in which the brightness match is performed photoelectrically. A sensitivity of $\pm 0.02 \text{ deg C}$ at 1063° C is achieved with a reproducibility of $\pm 0.1 \text{ deg C}$.

Introduction

ABOVE 1063° C , temperatures on the International Temperature Scale (Comité International des Poids et Mesures 1948) are based on the relation

$$J(T)/J(\text{Au}) = [\exp \{C_2/\lambda T(\text{Au})\} - 1][\exp \{C_2/\lambda T\} - 1]^{-1},$$

where $J(T)$ and $J(\text{Au})$ are the radiant energies per unit time per unit area per unit wavelength interval emitted by black bodies at the temperature $T^\circ \text{ K}$ and at the freezing point of gold $T(\text{Au})^\circ \text{ K}$ respectively.

In practice, the temperature scale is maintained as the current-temperature calibration of a tungsten filament in an optical pyrometer, the major limit on the accuracy of realization of the scale being the uncertainty in the visual brightness match. In an endeavour to improve this accuracy substantially, an optical pyrometer has been developed in which the brightness match is made using photoelectric detection. The instrument described below has proved to be at least an order of magnitude better than the conventional visual instrument.

General description of the pyrometer

In a visual disappearing filament optical pyrometer, a match is obtained when the brightnesses of the pyrometer filament and the adjacent image of the source are equal. This is usually determined by scanning the eye across the filament-source intersection and attempting to detect any discontinuity in brightness. The photoelectric instrument is based on a similar scheme, a small slit being made to oscillate

across the image of the filament-source intersection. A discontinuity in brightness is converted by a photomultiplier into a voltage which is then amplified, noise being reduced by the use of a phase-sensitive detector synchronized with the motion of the slit. A match is obtained by adjusting the filament lamp current for zero detector output.

The optical system of the pyrometer is shown in Fig. 1 and the block diagram of the electronics in Fig. 2. Details are as follows.

Optical system. The optical system is similar to that of a visual disappearing-filament optical pyrometer except for the use of a projection eyepiece. The objective lens forms an image of the external source in the plane of the filament; the eyepiece forming an enlarged image ($\times 5$) in the plane of the moving slit. A field lens behind the slit images the eyepiece aperture, which is made the limiting aperture of the instrument, on to the photocathode; the position of the image of the photocathode is thus independent of the motion of the slit. The range of wavelengths used is limited by an interference filter (Wild Type 8103), having a maximum transmittance of 40% at $6500 \text{ \AA}$ and bandwidth of $125 \text{ \AA}$ at transmittance of one-half maximum. The filter is inclined at a small fixed angle to the optical axis to eliminate multiple reflections.

All lenses are fixed; to permit optical alignment and focusing, the filament lamp and strip lamp source are driven transversely, vertically and longitudinally by micrometer as shown in Fig. 3.

Scanning mechanism. The slit has been made by evaporating an aluminium layer on to a cover slip, 0.4 in. (1 cm.) square, 0.005 in. (0.013 cm.) thick carrying a piece tungsten ribbon; the shadow of the ribbon left a clear opening $0.0846 \text{ in.} \times 0.0112 \text{ in.}$ ($0.215 \text{ cm} \times 0.0285 \text{ cm.}$). This is cemented to one arm of a tuning fork (426.6 c/s.), multiple reflections along the optical path being prevented by tilting the slit slightly.

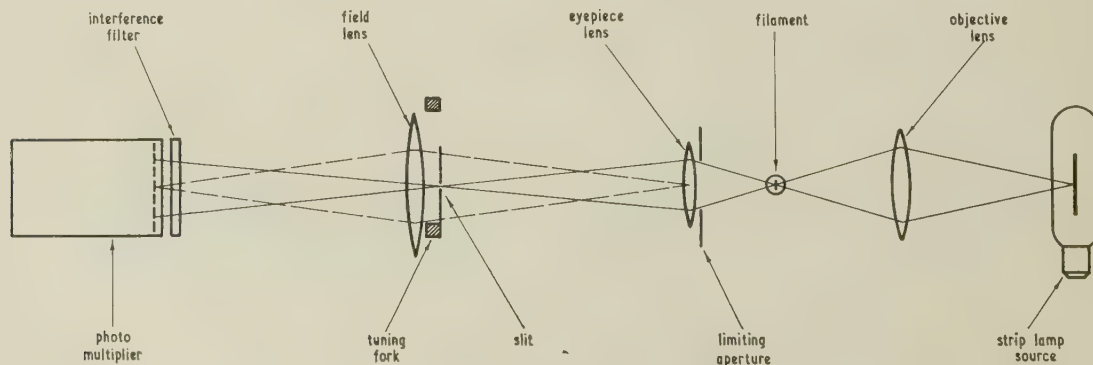


Fig. 1. Optical system of pyrometer.

The tuning fork forms the mechanical tuned circuit of a feedback oscillator, the driving and pick-up coils being 1000 Ω magnetic headphone coils complete with magnets, embedded in epoxy resin. The slit is attached to the arm near the

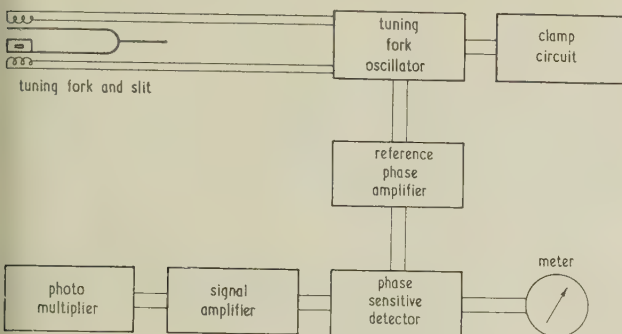


Fig. 2. Block diagram of electronic system.

pick-up coil since its motion is more nearly a pure sine-wave than that near the driving coil. To maintain the amplitude of scan of the slit at a constant value [0.011 in. (0.028 cm) peak to peak], a high-gain clamp circuit is incorporated, the amplitude of the signal on the grid of V_{3B}



Fig. 3. External view of pyrometer showing micrometer adjustments.

Fig. 4) increasing until it exceeds the set cathode level. As soon as this happens, large pulses are fed to the diode D which controls the gain of the oscillator and clamps the output at the set level.

Photomultiplier and amplifier. The photomultiplier, E.M.I. Type 9558, has a divider constructed of low-noise resistors connected to a 1900 v d.c. regulated power supply (The Isotope Developments e.h.t. unit, Type 532/A). The multiplier is completely enclosed in an iron shield with all connections shielded.

The amplifier circuit is shown in Fig. 4. A 10 000 Ω wire-wound resistor R_{17} is used as the photomultiplier load, representing a compromise between gain, Johnson noise and the ability to use d.c. coupling to the amplifier. Low impedances are used in the first stage and a stepped attenuator R_{19} removes the contact noise normally found with sliding potentiometers. In practice, the noise level of the amplifier cannot be detected on the highest gain setting and with the power supply to the photomultiplier turned off.

Phase-sensitive detector. The amplifier output is fed to a phase-sensitive detector. Several types of detector were tried using valves and germanium diodes, but none was sufficiently stable either in sensitivity or zero. In this particular appli-

cation, the requirements placed on the short-term stability of the detector are most stringent. Fast random fluctuations are permissible since they are removed by the integrator (R_{16} , C_{13} and C_{14}) which follows the detector.

The system adopted is a mechanical switch (Bristol

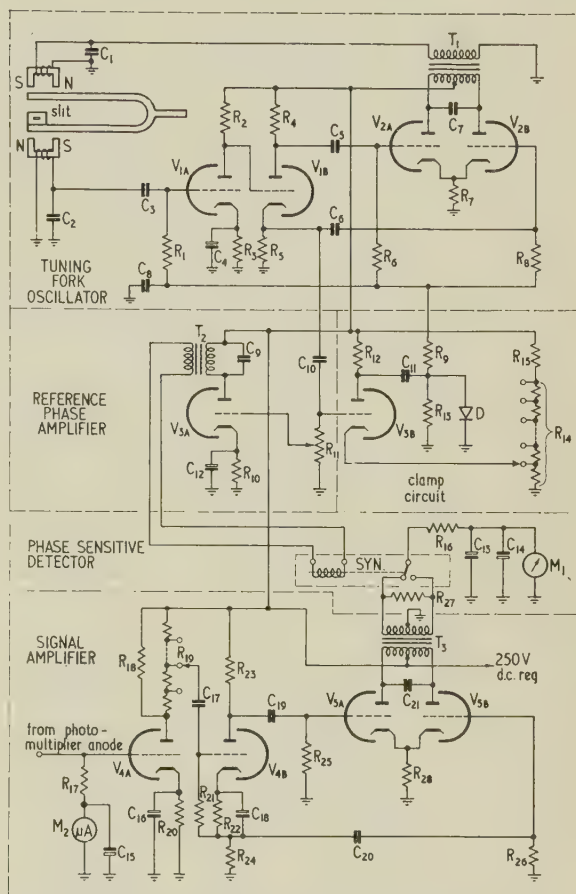


Fig. 4. Circuit diagram of the pyrometer.

Resistors

- $R_1 = 1 \text{ M}\Omega$, $\frac{1}{2}$ w, carbon
- $R_2 = 220 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_3 = 2.2 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_4 = 22 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_5 = 22 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_6 = 330 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_7 = 330 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_8 = 330 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_9 = 100 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_{10} = 330 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_{11} = 270 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_{12} = 250 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_{13} = 100 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_{14} = 10 \times 220 \Omega$, $\frac{1}{2}$ w, carbon
- $R_{15} = 47 \text{ k}\Omega$, 1 w, carbon
- $R_{16} = 4.7 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_{17} = 10 \text{ k}\Omega$, 3 w, wire-wound
- $R_{18} = 22 \text{ k}\Omega$, 3 w, wire-wound
- $R_{19} = 10 \text{ k}\Omega$ (in twelve steps of 3 db)
- $R_{20} = 220 \Omega$, $\frac{1}{2}$ w, carbon
- $R_{21} = 100 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_{22} = 1 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_{23} = 22 \text{ k}\Omega$, 1 w, carbon
- $R_{24} = 22 \text{ k}\Omega$, 1 w, carbon
- $R_{25} = 470 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_{26} = 470 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_{27} = 3.3 \text{ k}\Omega$, $\frac{1}{2}$ w, carbon
- $R_{28} = 330 \Omega$, $\frac{1}{2}$ w, carbon

Capacitors

- $C_1 = 0.1 \mu\text{F}$, 200 v, paper
- $C_2 = 0.1 \mu\text{F}$, 200 v, paper
- $C_3 = 0.01 \mu\text{F}$, 200 v, paper
- $C_4 = 50 \mu\text{F}$, 25 v, electrolytic
- $C_5 = 0.01 \mu\text{F}$, 400 v, paper
- $C_6 = 0.01 \mu\text{F}$, 400 v, paper
- $C_7 = 0.01 \mu\text{F}$, 400 v, paper

- $C_8 = 1 \mu\text{F}$, 200 v, paper
- $C_9 = 0.01 \mu\text{F}$, 400 v, paper
- $C_{10} = 0.1 \mu\text{F}$, 400 v, paper
- $C_{11} = 0.1 \mu\text{F}$, 400 v, paper
- $C_{12} = 25 \mu\text{F}$, 25 v, electrolytic
- $C_{13} = 100 \mu\text{F}$, 12 v, tantalitic
- $C_{14} = 100 \mu\text{F}$, 12 v, tantalitic
- $C_{15} = 100 \mu\text{F}$, 12 v, tantalitic
- $C_{16} = 100 \mu\text{F}$, 12 v, tantalitic
- $C_{17} = 0.01 \mu\text{F}$, 600 v, paper
- $C_{18} = 100 \mu\text{F}$, 12 v, tantalitic
- $C_{19} = 0.01 \mu\text{F}$, 600 v, paper
- $C_{20} = 0.01 \mu\text{F}$, 600 v, paper
- $C_{21} = 0.01 \mu\text{F}$, 400 v, paper

Transformers. (All figures given at 400 c/s)

- T_1 : 2-w prim., $Z = 20\,000 \Omega$, c.t., $R = 1000 \Omega$
- Sec., $Z = 1000 \Omega$, $R = 50 \Omega$
- T_2 : 2-w prim., $Z = 10\,000 \Omega$ at 10 mA, $R = 1000 \Omega$
- Sec., $Z = 150 \Omega$, $R = 10 \Omega$
- T_3 : 2-w prim., $Z = 20\,000 \Omega$, c.t., $R = 600 \Omega$
- Sec., $Z = 10\,000 \Omega$, c.t., $R = 600 \Omega$

- M_1 : 5-0-5 μA
- M_2 : 0-50 μA

SYN: Bristol Synchroverter

D: OA79

Tuning Fork: $A = 426.6 \text{ c/s}$

V_1 - V_5 : 12AT7

Synchroverter) driven synchronously with the tuning-fork oscillator. This has not produced any detectable drift in zero over a period of use of 1000 hours and has a short-term stability of $0.01 \mu\text{A}$, which, at 1063°C , is equivalent to 0.01°C . As well as being a linear detector, it shows no change in zero with change in amplitude of the reference

Errors

To evaluate the instrument as a precision temperature measuring device, it is necessary to consider sensitivity, stability and reproducibility separately. Fig. 5 shows the instrument sensitivity as the standard error of ten readings taken without altering the instrument adjustments. At 1063°C , ten similar sets of ten readings taken after readjustment of the micrometers have yielded, for the stability of the instrument, a standard error of $\pm 0.07^\circ\text{C}$. The reproducibility, assessed by dismantling and reassembling the optical components before each readjustment, amounts to $\pm 0.1^\circ\text{C}$, a figure which includes the above stability contribution.

The limit of the sensitivity is set by the signal-to-noise ratio of the whole apparatus. The major component is the shot noise in the photomultiplier, which has been selected because its photocathode (Sommer 1955) is of a type giving relatively high quantum efficiency at $6500 \text{ \AA}$.

The largest component error of the stability is the difficulty in optimizing the filament height, the variation in match on either side of optimum being approximately 0.1°C per 0.0001 in. (0.00025 cm) change in filament height.

Conclusions

Comparison of the sensitivity of the photoelectric and visual optical pyrometers (Fig. 5) shows clearly the gain which has been made by eliminating visual matching. At the gold point, the reproducibility using a visual optical pyrometer can scarcely be reduced below $\pm 1.5^\circ\text{C}$; the corresponding reproducibility for the photoelectric instrument is $\pm 0.1^\circ\text{C}$.

Because of the considerable reduction in this component of the overall uncertainty in the realization of the scale, other components, which could be considered negligible with the visual instrument, become of major importance with the photoelectric pyrometer. Consequently a redetermination of all auxiliary measurements (for example, true emissivity of a 'black body', spectral response of photomultipliers and spectral transmittance of optical components) must be undertaken to use the full potential of this new instrument.

It is clear that the photoelectric pyrometer will permit the realization of the International Temperature Scale above 1063°C to an accuracy one order of magnitude better than that attainable by visual optical pyrometry.

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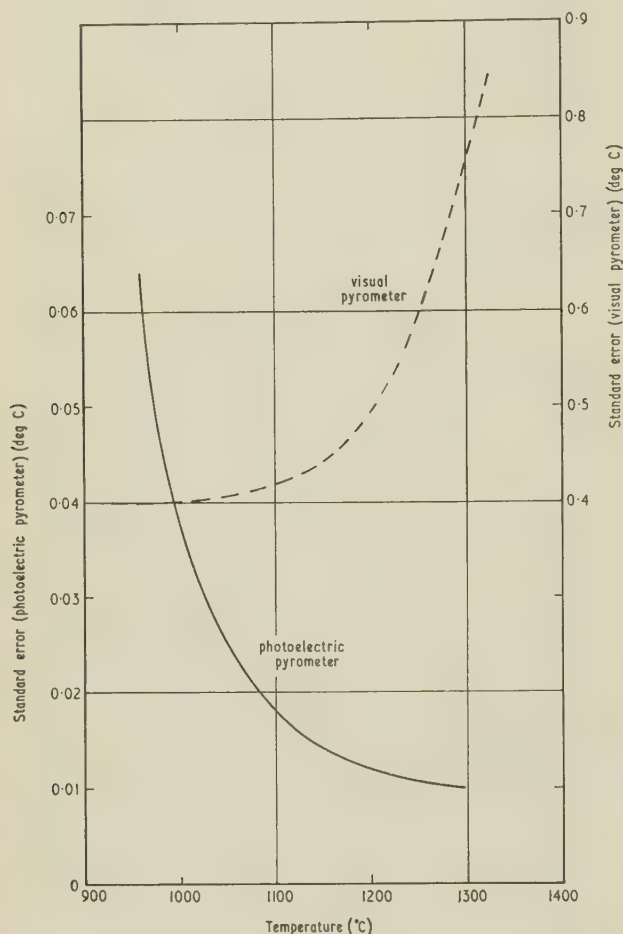


Fig. 5. Comparison of sensitivities of visual and photoelectric optical pyrometers.

voltage. Changes of phase from optimum between the instantaneous location of the slit and the make-and-break action of the Synchroverter produce changes in signal-to-noise ratio only.

Design for a three-circle X-ray goniometer

by R. W. H. SMALL, B.Sc., Ph.D., and S. TRAVERS, Chemistry Department, The University, Birmingham, 15

MS. received 11th October 1960

Abstract

Using the scheme first described by Furnas and Harker, for the collection of three-dimensional intensity data from a single crystal in which the motion of the counter tube is restricted to a horizontal plane, a comparatively simple instrument has been designed. Particular attention has been given to the design of simple bearings which are free from backlash and wear, and which permit the recording of diffracted beams up to an angle of 2θ of 165° . The instrument has provision for scanning and recording integrated intensities over an arc of 4° . Some details of performance are given.

ALTHOUGH the advantages of counter measurements of single crystal intensities in x-ray analysis are now generally recognized, more widespread use of counters for this purpose has probably been hampered by the lack of suitable commercial instruments in this country. Such an instrument may be constructed in a reasonably well equipped instrument workshop at a comparatively low cost.

The instrument described here makes use of the principle first discussed by Furnas and Harker (1955), the use of which has later been summarized by Arndt and Phillips (1957). Suitable orientation of a single crystal about three axes brings each crystal plane into a position to reflect x-rays in a single (horizontal) plane, which is the plane of rotation of the measuring counter.

Using the nomenclature of Arndt and Phillips (1958), the spherical polar coordinates of reciprocal lattice points referred to suitable crystal directions are ϕ , χ , and ρ ($2 \sin \theta$), corresponding axes of rotation in the instrument are ϕ , χ and θ . The axis 2θ of the measuring counter is coincident with the vertical axis θ , this axis carries the horizontal χ axis about which in turn the ϕ axis carrying the crystal rotates (in a vertical plane). The basic mechanical requirements are that: (i) the axes ϕ , χ , θ intersect in a single point (the crystal); (ii) the axis ϕ be perpendicular to the axis χ ; (iii) the axis χ be perpendicular to the axis θ ; (iv) the collimated pencil of x-rays pass through the point of intersection of the three axes and be perpendicular to the θ axis; (v) in order to investigate a hemisphere of reciprocal space, unrestricted rotation about the ϕ axis is required and 90° of rotation about the χ axis starting from the vertical position of the ϕ axis, together with 90° of rotation about the θ axis starting from the χ axis parallel to the x-ray beam; (vi) the design of the bearings particularly of the χ axis has to be such as to allow the diffracted x-rays to pass from the crystal over a range of 2θ of nearly 180° into the counter.

The main instrument bearings are shown in the figures, plain tapered bearings of dissimilar metals (brass and gun metal) have been used for the ϕ , χ , θ and 2θ axes. Bearings of this type if carefully machined and lapped are almost entirely free from play and wear and have low friction. The θ and 2θ bearings A, B respectively with a common part C of gun metal fixed to the base plate D, are of massive con-

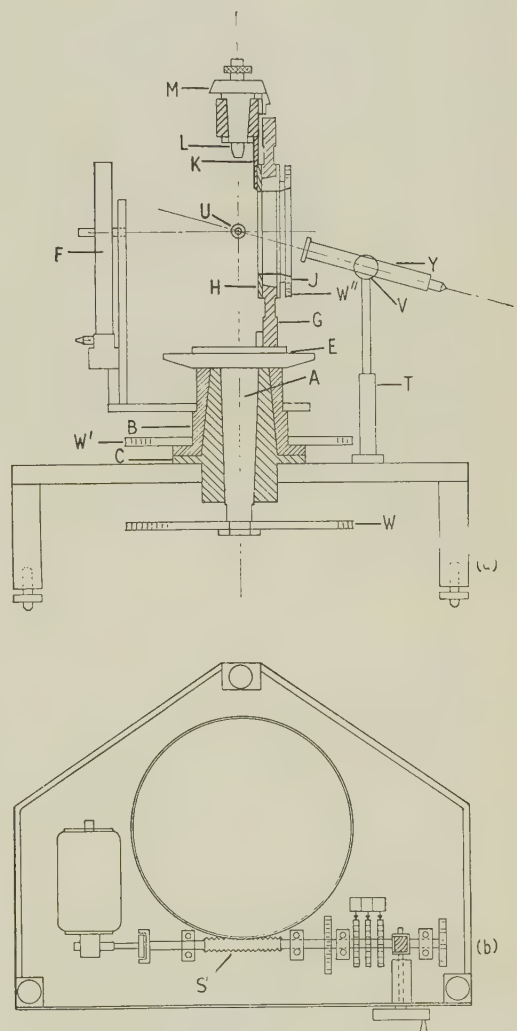
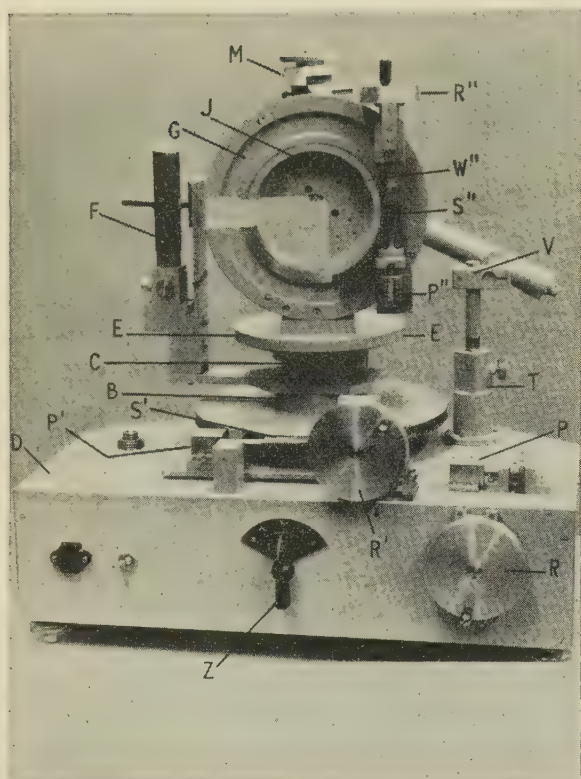


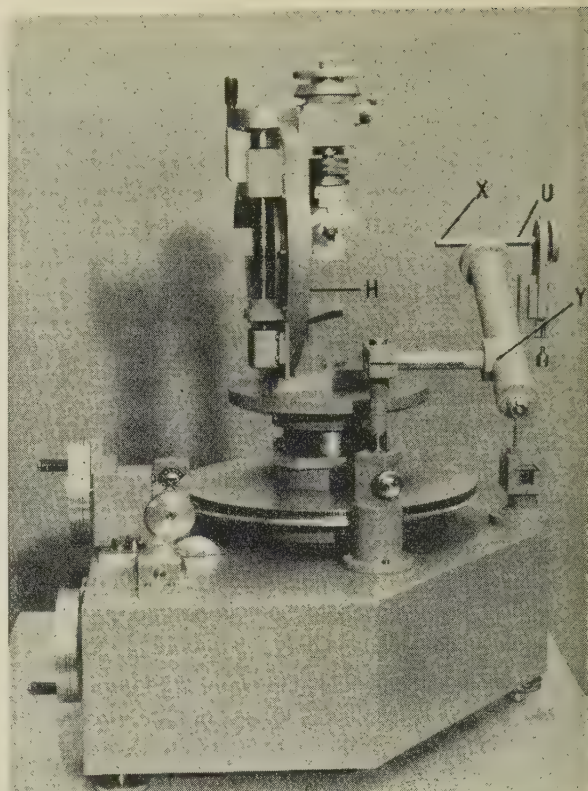
Fig. 1. (a) Diagrammatic elevation of the three-circle x-ray goniometer; (b) plan view of base showing the main components on the underside. Note: all details are not shown in these sketches.

struction since the table E of the θ circle carries the fixed and moving parts of the χ and ϕ circles. The 2θ bearing although in this instance carrying only a comparatively light proportional counter F, could carry a much heavier detector; in addition both bearings carry heavy worm wheels W and W'.

To the table E is fixed the outer gun metal C-shaped ring G of the χ circle, the piece being cut out to permit x-rays to pass from the crystal to the counter at higher θ values; distortion of the ring on slitting is avoided by careful annealing. The inner moving member of the χ circle is in two parts H and J screwed together, the worm W'' being cut on J; the bearing surface between H and G is tapered. Rather more than a quadrant is cut from the disks making H and J, so



(a)



(b)

Fig. 2. (a) and (b) Two views of the instrument.

that rotation over 90° of the assembled inner section HJ is possible without obstructing the x-ray beam. On the part H is mounted the outer bearing K of the ϕ circle axis, also plain tapered; the inner part L carrying the crystal arcs also includes a 'height adjustment' to bring the crystal to the point on the ϕ axis intersected by the χ axis. The inner part of this bearing carries the 360° vernier scale M with fine screw adjustment; settings may be made to 0.1° .

The worm wheel W'' on the χ circle has 180 teeth, settings may be made to within 0.2° using the rev counter P'' on the worm screw S'' or to within $5'$ using the divided drum R''. The worm wheels W and W' each have 360 teeth and are operated by spring loaded worms S and S'; drums R, R' divided in minutes and linked to the worms by 1 : 1 spiral bevel gears, together with revolution counters P, P' enable the angles θ , 2θ to be set.

The collimator U is provided with the four degrees of freedom necessary for its correct alignment; it is of conventional design with circular apertures. An extension to the collimator tube X carries the beam catcher (not shown in the photographs) which has to be removed over some extreme ranges of angular setting, and contains within its length a piece of nickel foil which serves the dual purpose of β filter (for Cu K α radiation) and to provide a diffracted beam for operation of the monitor circuit. The monitor (in this instrument a Geiger tube) Y, is supported on an adjustable arm V carried in the base clamp T; it may be removed and replaced by a microscope for alignment of the crystal.

The counter and crystal may be rotated about the vertical axis independently or geared together in a 2 : 1 ratio. The base of the instrument contains a low-speed motor connected to the worm S through a magnetic clutch; the shaft bearing the worm also carries toothed wheels with 20, 30 and 40 teeth

which operate micro switches. These in conjunction with the monitor and a suitable relay pack permit automatic stepwise scanning and integration through crystal reflections, portions of the background, as used by Arndt and Phillips (private communication). Such scans may be over angular ranges of between one and four degrees depending upon the toothed wheel selected by the switch and upon the design of the monitor control circuit.

The instrument described has been constructed by one of us (S.T.) and used in the collection of intensity data for three structure determinations (to be published later) to date. It has been found possible to measure integrated intensities from about 40 crystal planes per day with good reproducibility. In practice, using Cu K α radiation for organic crystalline scans of 2° through the reflecting position for $\theta \leq 65^\circ$ and of 4° for $\theta > 65^\circ$ (to cover $\alpha_1 - \alpha_2$ resolution) have been used. For such scans the 2θ , θ circles have been linked 2 : 1 and a counter aperture of about 4° used. It is of course necessary to know values of θ , χ , ϕ in advance, calculation from the cell constants using a suitable computer programme being the most convenient source. A small loudspeaker connected to the output of the counter amplifier is convenient for location of diffraction maxima; provided the setting angles are accurate to within 0.2° excessive hunting for maxima may be avoided and setting accomplished in approximately one minute.

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Sensitive method for measuring small rotations of a distant object

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MS. received 11th January 1961

Abstract

The application of a polarimetric system to measurements of the relative orientation of two units separated by a large distance is described. A sensitivity of 0.1 minute of arc is easily obtainable, with a separation of 2000 ft.

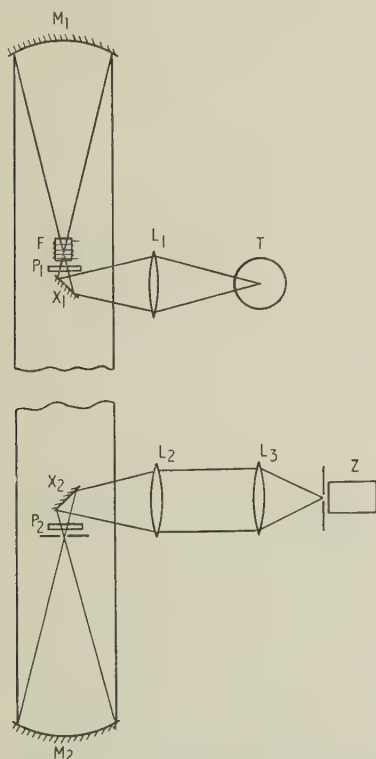
In a recent note, King and Gates (1959) described how the basic principle and components of a photoelectric saccharimeter could be applied to measuring the relative rotation of two units separated by a comparatively small distance (i.e. up to approximately 50 ft). The following note gives details of an experiment, in which the method was shown to be practicable with the units separated by the much larger distance of 2000 ft.

The chief difficulty which arises with a large separation between the units is one of collecting sufficient energy and this has been overcome by using two relatively large concave mirrors; this, in fact marks the essential difference between the new system and the previously described arrangements. The optical system is shown in the diagram. A 12 v, 48 w,

tungsten filament lamp T is imaged by means of lens L_1 and mirror X_1 at the focus of the concave mirror M_1 (8 in. diameter, 40 in. focal length). The collimated beam from this mirror is then collected by the second large concave mirror M_2 (10 in. diameter, 17 in. focal length), the light finally being brought to a focus at the photomultiplier Z by means of mirror X_2 and lenses L_2 and L_3 . Ideally the two mirrors M_1 and M_2 should be of the same aperture and focal length, the two used being the only suitable ones readily available. The Polaroid polarizer and analyser P_1 and P_2 , which are to be orientated relative to each other, are situated near the foci of M_1 and M_2 respectively. The Faraday cell modulator F can be located at the focus of either concave mirror, provided, of course, its position in the light path is between the polarizer and analyser. It will be noted that the polarizer, analyser and Faraday cell can have relatively small apertures by placing them at the foci of the concave mirrors, whereas if used in the collimated beam, they would require impractically large apertures. For convenience of operation, both concave mirrors and their associated components were actually placed in the same room, with a plane mirror situated 1050 ft away, resulting in an effective separation of 2100 ft.

The two concave mirrors are used on axis, the small obstruction from the polarizers, plane mirrors, Faraday cell and their respective mounts giving an insignificant loss of energy. It will be noted that the reflections at the concave mirrors occur in the light path between the polarizer and analyser, which are, themselves, not in a collimated beam of light. This results in a twist of the vibration plane of the light, which varies over the aperture of the system (see Gillham and King 1961). The effect is, however, independent of the separation distance between the two units and should not interfere with the efficient functioning of the method.

Due to the difficulty in providing adequate shielding from daylight, the measurements were carried out at night. The polarizer and analyser were orientated in the crossed position, and the Faraday cell modulator (a 1.6 in. long core of Chance SDEDF glass No. 030181, surrounded by a coil of 2300 turns of 26 s.w.g. enamelled copper wire) was supplied with an alternating current (0.5 A r.m.s., 50 c/s) to give a modulation angle of $\pm 3^\circ$. Any departure from the exact crossed position of the polarizer and analyser resulted in a 50 c/s signal from the photomultiplier; this was amplified, rectified and further amplified, the final output being measured by a microammeter. For calibration purposes, the polarizer was rotated through small angles, which were accurately measured using an auto-collimator to observe the reflection from a plane mirror attached to the polarizer mount; simultaneously the change in reading of the microammeter was recorded. Then, with the polarizer fixed in position, the peak output noise level was measured over a period of



Optical arrangement for rotation measurements over a large distance.

approximately two minutes and converted to units of angular rotation. In this way, it was found that with the lamp operating at its correct wattage (48 w), the peak output noise level corresponded to a rotation of ± 0.4 minute of arc. On severe overrunning of the lamp (100 w), the peak noise level was reduced to ± 0.2 minute of arc. A change of orientation of polarizer or analyser by 0.1 minute of arc was therefore easily detectable.

In the above system, the effective source size is only about 0.02 in. in diameter, and thus an ordinary coiled filament lamp is not the most efficient light source. The use of a source of extremely high brightness, for example a d.c. run 'point source' mercury arc, would increase the illumination level at the photomultiplier and, consequently, decrease the output noise level. Furthermore, by the use of suitably placed screening and apertures to reduce the amount of stray light, a high brightness lamp should enable the system to function quite satisfactorily in daylight.

While the above arrangement is quite suitable for problems relating to the orientation of one unit relative to the other (i.e. measurement at null point), for the accurate measurement of small rotations it has the disadvantage that the calibration (i.e. rotation in terms of output current) will depend on the stability of the power supplies and the lamp brightness. This disadvantage can however be readily overcome by compensating for the 'out-of-balance orientation', and thus effectively using the system at the null position. The compensation can be achieved either automatically using a second high impedance Faraday cell, fed directly from the output of the electronics (see King and Gates 1959), or manually by feeding a measured direct current to the existing

Faraday cell modulator. Furthermore, although the experiments were carried out at only one distance between the two units, their relative orientation to give zero output from the electronics should be independent of this separation, apart from the effect of the earth's magnetic field; for very large separations, it may be necessary to apply a correction for the Faraday effect in air, resulting from this field. Thus assuming the horizontal component of the earth's magnetic field to be 0.18 oersted and to be parallel to the light beam between the two concave mirrors, this effect will produce a rotation of approximately 0.04 minute of arc per 1000 path length.

The applications of systems of this type would appear to be varied. They would include the direct static and dynamic measurement of torsional strain in large structures, the continuous recording of angular shifts of a body not readily accessible during measurement, and orientation measurements of two units separated by a large vertical distance (e.g. in a pit shaft). The last mentioned application may be particularly important, as more conventional measuring methods are not readily available.

Acknowledgment

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Automatic compensation for thermal e.m.fs and galvanometer zero drift in a feedback fluxmeter

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MS. received 21st December 1960

Abstract

Slow drift of a feedback fluxmeter is prevented by resistive feedback in addition to the differentiating circuit. Before a measurement the resistive path is opened whilst maintaining the voltage for zero drift.

VARIOUS fluxmeters have been described which employ a galvanometer arranged so that its deflection produces an electric signal S which after amplification to a value AS is differentiated and fed back in series opposition to the galvanometer input.

It is then simply shown that if A is large enough AS is almost exactly proportional to $\int e dt$, where e is the instantaneous e.m.f. applied in series with the galvanometer and feedback element. If e is generated in a coil linking a varying flux ϕ , then a change in flux $\Delta\phi = \int e dt = \Delta AS$.

In all these instruments the galvanometer deflects a light beam which falls on a pair of phototubes to give a difference signal approximately proportional to the angular deflection of the galvanometer.

Differentiation may be achieved by a mutual inductor M in which the secondary e.m.f. is $M di/dt$, where i is the primary current (Edgar 1937, Cioffi 1950, Brockman and Steneck 1954, Kapitza 1955), or the same function may be performed by an RC network to give a voltage $RCdV/dt$ across the resistor R (Dicke 1948, Berge and Guderjahn 1954, Tompkins and Jonng 1956).

The feedback fluxmeter has the following advantages over the Grassott fluxmeter: (i) the sensitivity may be changed by varying R , C or M , instead of using a shunting potential divider, the ratio of which depends on the source impedance; (ii) an electrical output is obtained which may be used to operate a recorder for tracing hysteresis loops automatically; (iii) great sensitivity can easily be obtained, limited only by the instability of the input circuit.

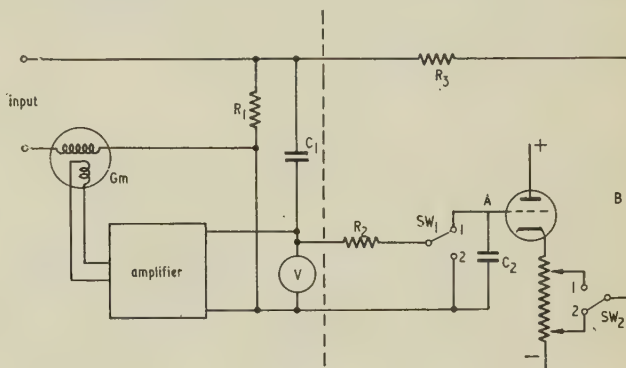
It is noted in the references that, provided care is taken to ensure mechanical steadiness in the galvanometer, the main source of instability is due to thermal e.m.fs and lack of long-term zero stability in the galvanometer.

In most previous instruments a small e.m.f. derived from a dry cell is adjusted manually to counteract thermal e.m.fs. In practice this involves making an adjustment for zero rate of drift immediately before taking a measurement and this adjustment becomes critical when high sensitivity is used.

By means of a modification to a conventional RC feedback loop this adjustment can be made automatically. Before a measurement is made, SW_1 (see Figure) is in position 1 to charge C_2 through R_2 and to complete a resistively coupled negative feedback path via R_2 , R_3 and R_1 . Such a circuit maintains V constant and very close to zero. Before a flux change is to be measured SW_1 is switched to position 2 and the voltage for zero drift at the instant of switching is maintained constant across C_2 for the duration of the measure-

ment. Obviously, compensation is only correct if the thermal e.m.fs also remain constant over this interval.

By bringing V to zero, the circuit also serves as a zeroing



Drift compensator. Gm, galvanometer-modulator; 'amplifier', amplifier and demodulator; V, indicating voltmeter.

device; Dicke (1948) similarly used a simple resistive circuit without charge storage for this purpose. Normally point B is adjusted to be at the same potential as A, but by switching SW_2 to position 2 a potential difference between A and B is introduced so that voltmeter V may be set to a centre scale position.

Considering the conventional feedback fluxmeter as an ideal integrator with time constant R_1C_1 , the addition of network R_2 , R_3 and C_2 results in a second-order system which can be shown to have critical damping when $R_3^*C_1/R_2C_2 = 4$ where R_3^* is equal to R_3 multiplied by the ratio of the voltage of point A to point B. It is noteworthy that damping is independent of the value of R_1 and is not affected as R_1 is changed for different ranges of sensitivity.

Automatic compensation has been applied to a feedback fluxmeter in which a light-beam galvanometer is replaced by a taut-suspension galvanometer-modulator excited at audio-frequency. With this arrangement the instrument can be portable and no delicate adjustments are required before use. Automatic compensation is particularly valuable when many measurements of short duration are to be made.

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Nuclear resonance magnetic field stabilizer

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Abstract

A nuclear resonance magnetic field stabilizer is described in detail. Circuit diagrams are included and the adjustment procedure is outlined for the particular application in which field fluctuations of one part in 10^3 have to be handled. An improvement by a factor of 100 in field stability is readily obtained.

1. Introduction

THE stabilizer described has been developed to combat variations of up to one part in 10^3 in the field of a commercial electromagnet. This magnet is of a type commonly available for magnetic resonance research and the stabilizer can, therefore, be used with many existing magnets. The pole cap diameter is 17.75 cm and the maximum air gap is 5.85 cm. With this gap a current of 10 amperes in 3700 turns produces a field of 6000 gauss.

The apparatus consists of a conventional crystal-controlled Pound-Knight-Watkins type spectrometer together with an

audio-frequency system providing field modulation and phase-sensitive detection. The resonance signal from protons is modulated at a frequency different from the main field modulation by the current in small coils surrounding the sample. The error signal, which is the output of the phase-sensitive detector, is fed to a compensating coil wound around one of the magnet poles.

Provision is made for operation of the spectrometer at other frequencies (5 to 30 Mc/s), thereby enabling the field of the magnet to be altered. Easily obtainable components and current miniature valves have been used throughout and the system has adequate overall gain so that the stage-by-stage performance is not critical: the equipment can therefore be readily copied. Stabilized power supplies are employed and d.c. valve heating is essential in the spectrometer.

2. Crystal-controlled spectrometer

The circuit, shown in Fig. 1, is based on the modified Pound-Knight-Watkins oscillator described by Blume (1958).

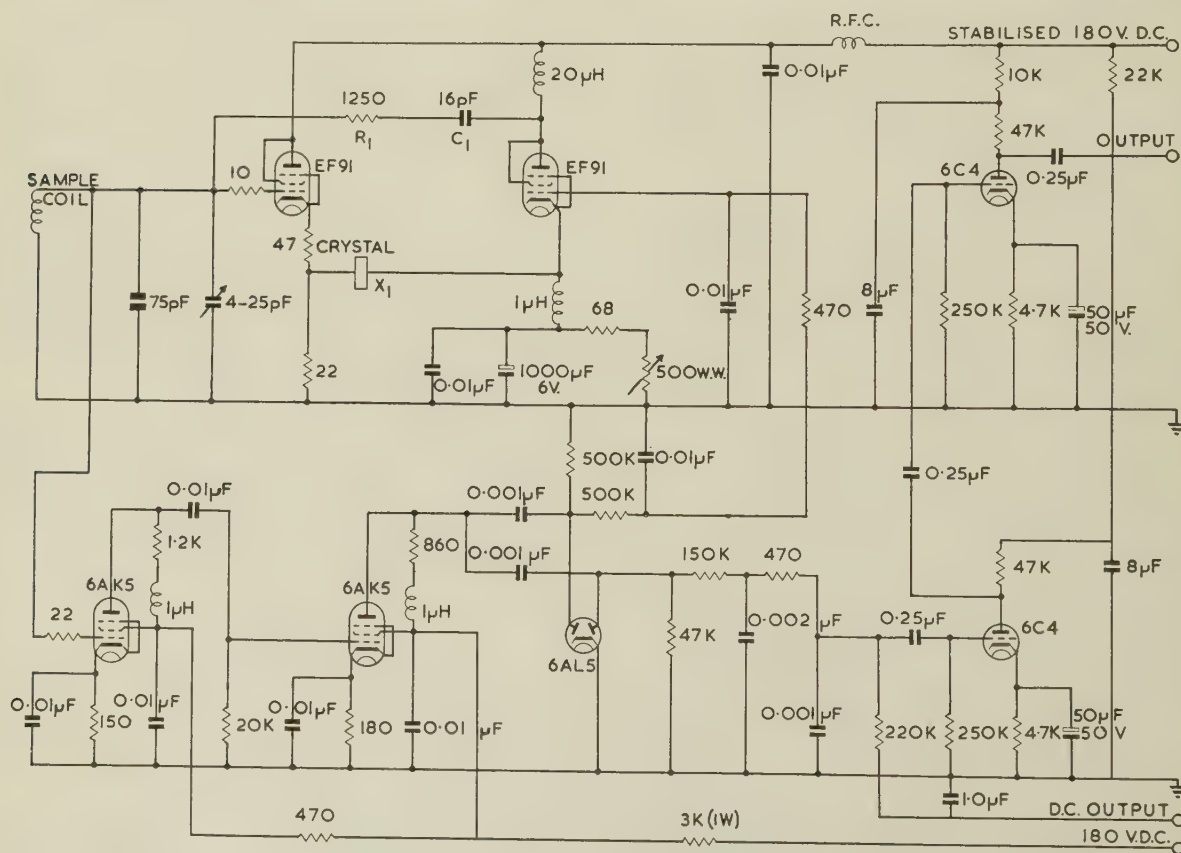


Fig. 1. Crystal-controlled spectrometer.

The 2MH Cathodeon crystal* is placed in the common cathode link as in the conventional 'Butler' crystal oscillator circuit. The driving impedance, of 22 ohms, is made small by using high gain valves (EF91); this also permits a smaller cathode-to-grid feedback. An improvement thereby results in the overall signal-to-noise figure of the spectrometer, the optimum value of which occurs with about 250 mv across the tuned circuit. The liquid paraffin sample, of volume 6 cm³, is contained in a glass tube on which is wound the radiofrequency coil. This and the r.f. lead are inside a $\frac{3}{8}$ in. dia tube which serves as an electromagnetic screen and the earth return for the r.f. current.

It was found that there was a detectable day to day variation of the magnetic field distribution over the gap, giving rise to a small but significant shift of the magnetic field at the sample under investigation. To minimize this, and to avoid the need for a cycling procedure after switch-on, the stabilizer

circuit depends on the response time of the overall feedback loop. The rectified radio frequency is monitored at the signal detector and this indicates the voltage across the sample coil. The two audio-frequency amplifier stages give a combined gain of about 100.

3. Audio-frequency system

The audio-frequency system consists of an oscillator, tunable over a small frequency range, a power amplifier for field modulation and a narrow bandwidth audio amplifier (Punnett 1950) followed by a Schuster phase-sensitive detector with cathode follower output to the correction coil.

The audio-frequency generator (Fig. 2) is a standard asymmetric RC type oscillator with a simple level control device in the positive feedback line. The two advantages of using the standard 250 v, 25 w pigmy lamp for this purpose

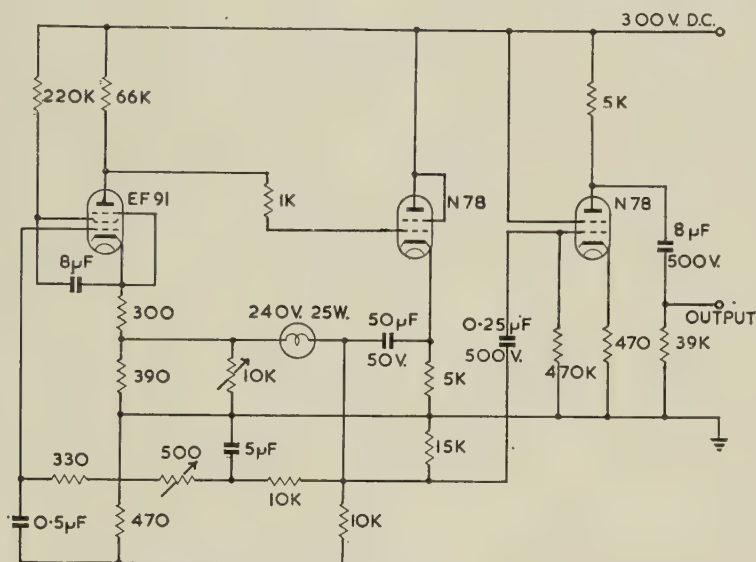


Fig. 2. Audio-frequency generator.

is placed as close to the experimental probe as possible consistent with having a proton linewidth equal to the range of control necessary. In our application it was necessary to have control over several gauss. To avoid modulation of the magnetic field over the whole gap, two small modulation coils are carried in grooves in a Perspex former which fits around the outside of the brass screening tube. Each has a mean diameter of 2 cm and consists of 24 turns of 26 s.w.g. enamelled copper wire. Together these give a peak-to-peak modulation of 7.5 gauss/ampere; in practice the modulation must be somewhat less than the linewidth of the proton resonance and the optimum current for our application is 0.2 amperes. To drive the signal and automatic level control diodes sufficiently a gain of at least 10 from the r.f. amplifier is necessary. Below 15 Mc/s this is achieved with two untuned stages. For operation at 20 Mc/s and above, however, an additional stage of gain is required. The response time of the level control diode smoothing circuit has been kept as short as possible without allowing the feedback voltage to follow the modulation period. Reduction of this time constant is desirable since the degree of 'hunting' of the correction

are that it is less sensitive to room temperature variations and that it is readily available. The frequency is adjusted by the 500 Ω potentiometer and the frequency range covered with the components shown is from 205 to 350 c/s. The level of feedback is adjusted by the 10 k Ω potentiometer and must be kept as low as possible consistent with stable oscillation. Excessive feedback results in too large an amplitude of oscillation with consequent distortion. Some frequency drift occurs on warm-up, although this is minimized by using adequately rated components and high stability resistors; approximately 30 minutes running is desirable before tuning the audio oscillator to the centre of the narrow audio passband. An output of about 20 volts peak-to-peak is available and this is adequate to drive the switch valves in the Schuster circuit through a 1 : 3.5 C.T. transformer.

The circuit of the modulation amplifier, which employs only a single triode-pentode, is shown in Fig. 3. Full constructional details are given in *Circuits for Audio Amplifiers* (1959). To avoid distortion the primary inductances of the output transformer (5000 Ω primary loading, 0.1 Ω secondary) and the transformer (1 : 3.5 C.T.) used in the simple phase-changing network forming the input circuit, must be at least 20 H if operation is envisaged at modulation frequencies less than 100 c/s.

* The authors have found that some crystals are appreciably more noisy than others and selection is desirable.

Two stages of amplification (Fig. 4) precede the narrow bandwidth audio amplifier which uses a symmetrical twin-T network in the negative feedback line. This network has zero transmission at the modulation frequency ($1/4\pi CR$) and has a maximum selectivity when the filter is driven by a cathode follower and feeds into an unloaded valve grid. For this application a very high Q is not desirable since this not only requires a highly stable audio oscillator but also contributes to 'hunting' of the stabilizer. The twin-T filter used peaked at 328 c/s with a bandwidth of 9 c/s.

The h.t. supply to the switch valve anodes of the phase-sensitive detector is taken from the unstabilized line and regulated by two gas-filled stabilizer valves operating in

series. This avoids a small spurious d.c. output which arises from a ripple on the h.t. line at the modulation frequency.

The d.c. output of the Schuster circuit is fed to C_1 , a coil wound on the magnet pole, through a cathode follower which acts as an impedance matching device. One of the modulation coils fitted by the manufacturers of the magnet has been used. This has 3000 turns and a resistance of 400 ohms. One milliampere through the coil shifts the field by approximately one gauss and the 3.5-0-3.5 mA m.p. conveniently monitors the correction in gauss being applied by the proton stabilizer.

By keeping the circuit response time reasonably short it was found possible to operate successfully without

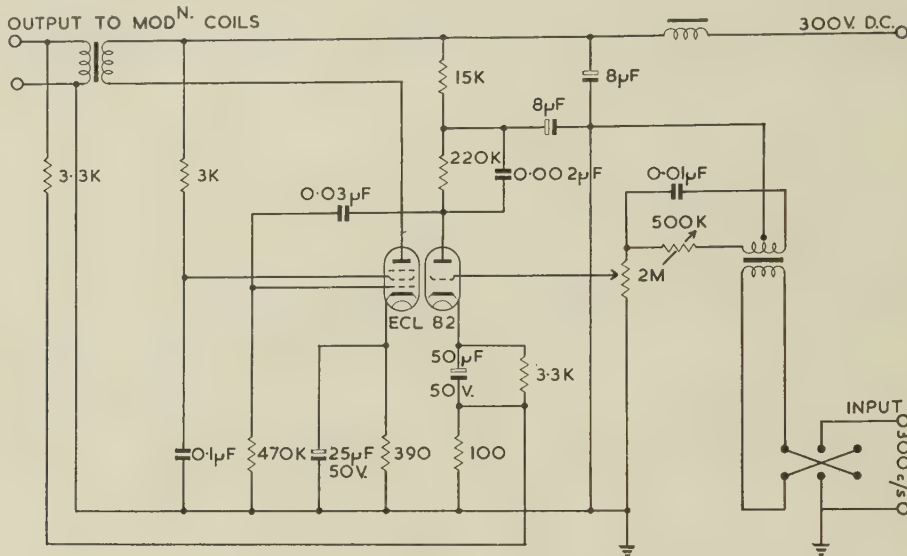


Fig. 3. Modulation amplifier and phase-shifter.

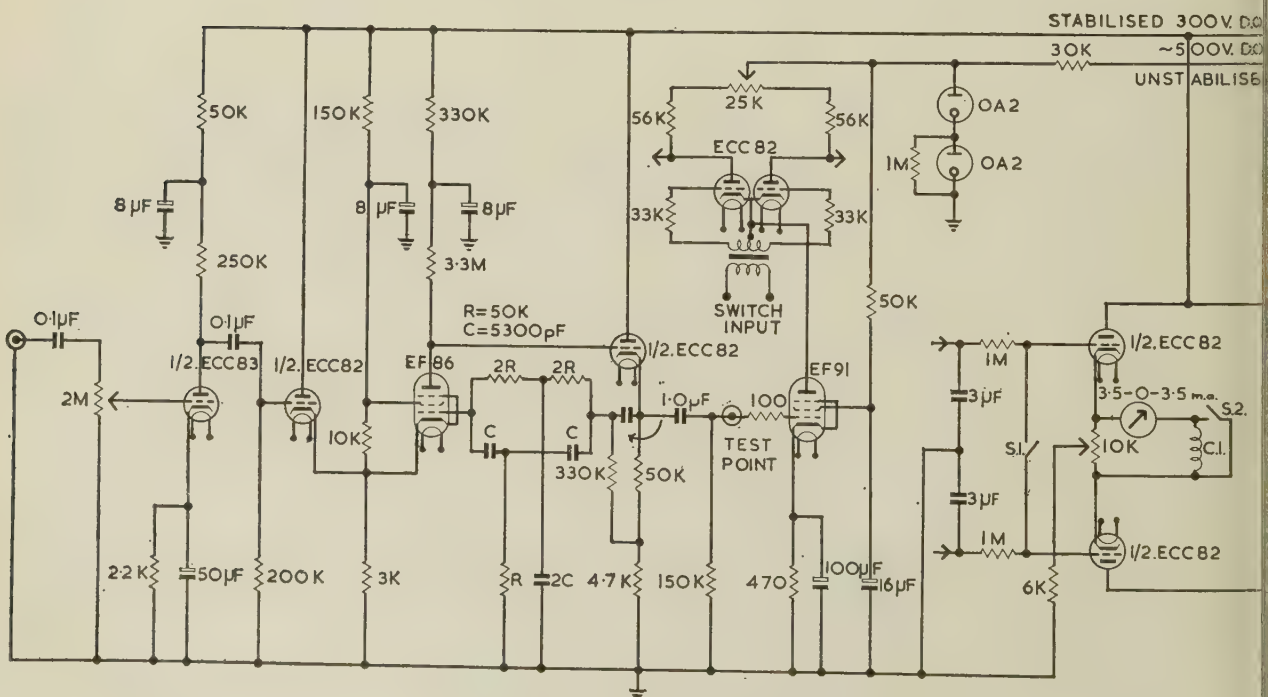


Fig. 4. Narrow bandwidth audio amplifier and phase-sensitive detector.

'antihunt' circuit. This, if required, would be placed between the output of the Schuster circuit and the cathode follower. More gain would then be needed to offset the attenuation introduced. A discussion of suitable 'antihunt' circuits is given by Pearson (1957).

4. Operating procedure

After a warm-up period, the crystal oscillator is tuned by monitoring the d.c. output from the signal detector with a μ A meter. A maximum reading on this meter indicates minimum pulling of the crystal oscillator and a reading of μ A is equivalent to about 250 mv radio frequency across the sample coil. The frequency of the audio oscillator is justed by feeding its output directly into the audio unit and observing the output of the narrow band amplifier on an oscilloscope. The level of field modulation is set to about one half the linewidth expected.

The input grid of the audio amplifier unit is grounded by setting the gain to zero and S_1 and S_2 are closed. The output cathode follower is balanced (zero on the milliammeter) by justing the 10 k Ω potentiometer. S_1 is opened and the huster switch tube loads are balanced similarly by adjusting the 25 k Ω potentiometer.

The audio gain is now increased until a little noise is visible on the output meter. The main magnetic field is then varied until a signal is observed, and the phase of the switch voltage is adjusted to give maximum signal peak-to-peak. The main field is set to the peak absorption value, which is indicated by

zero deflection on the milliammeter. S_2 is opened and the audio gain increased until control is achieved. The 180° phase shift switch (in the input circuit the power amplifier) may need to be thrown. Initially the degree of control is best checked by observing a strong resonance signal from independent equipment and changing the main field by known amounts. For our application field fluctuations are of the order of ± 3 gauss and it is found that a change of this amount in the main field is compensated to within 0.1 gauss. This is adequate for most wide line studies in nuclear magnetic resonance and almost all work in electron spin resonance. If the static field drifts slowly with time, it is necessary to reset occasionally the main field control so that the stabilizer is working approximately in the middle of its range.

Acknowledgments

This work was undertaken whilst one of us (G. J. J.) held a traineeship from the Department of Supply, Commonwealth of Australia, which he gratefully acknowledges.

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Selected Papers on Stress Analysis, presented at The Institute of Physics Stress Analysis Group Conference, Delft, 1959. Pp. 114 (London: Chapman and Hall Ltd. for the Institute of Physics, 1961).

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U.S. National Bureau of Standards

The U.S. National Bureau of Standards has recently issued the following publications. *Research Highlights of the National Bureau of Standards, Annual Report 1960*, price 5 cents. *Precision Measurement and Calibration*, N.B.S. Handbook No. 77, issued in three volumes: Volume I, *Electricity and Electronics*, price 6 dollars; Volume II, *Heat and Mechanics*, price 6.75 dollars; Volume III, *Optics, Metrology and Radiation*, price 7 dollars. *Report of the International Commission on Radiological Units and Measurements (ICRU) 1959*, N.B.S. Handbook No. 78, superseding Handbook No. 62, price 65 cents. *Climatic Charts and Data*

of the Radio Refractive Index for the United States and the World, N.B.S. Monograph No. 22, price 2 dollars. All these publications are available from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C., U.S.A.

Noble Metal Thermocouples

A third edition of *Noble Metal Thermocouples* has been published by Johnson, Matthey & Co. Ltd. The book describes the development of the noble metal thermocouple, its applications in steelworks, foundries and glassworks and methods of calibration. Curves of temperature against e.m.f. are given for many types of couple incorporating alloys of the platinum group metals and a chapter describes the chief causes of deterioration in service. A new feature of the present edition is a short section summarizing the behaviour of the many thermocouple combinations that have been proposed from time to time, and recommending those most suitable for particular applications. The book is available free on application to: Johnson, Matthey & Co. Ltd., 73-83 Hatton Garden, London, E.C.1.

A sensitive electrostatic meter with a balanced reed

by Y. L. YOUSEF, M.Sc., Ph.D., and Miss S. A. ZAHER, B.Sc., Physics Department, Faculty of Science, University of Cairo

MS. received 26th October 1960

Abstract

A new electrostatic meter is described for measuring by a null method resistance, capacity, power loss and power factor over a considerable range of values at mains frequency. The action of the device depends on the vibrations which are set up in a thin aluminium reed initially at rest under the influence of two opposite alternating electrostatic forces. It is arranged that the quantity we wish to measure upsets the equilibrium in these forces, but balance may be restored to 10^{-4} by the adjustment of a potentiometer and/or a resistance. The theory is discussed and typical examples of the various applications are given.

Introduction

THE most popular methods of measuring resistance, capacity and power factor employ a.c. bridges of suitable design, such as some version of the Schering bridge. For direct measurement of a.c. power loss, wattmeters of the dynamometer type or of the electrostatic type are frequently used, the latter type being an adaptation of the quadrant electrometer particularly suited for the determination of small power dissipation at high voltage.

The null device to be described may be used for a variety of electrical measurements such as resistance, capacity, power loss and power factor in condensers. It has been developed as a result of the need for a convenient means of determining resistivity and loss angle of powders at mains frequency. Its function is based on the electrostatic forces between a metal strip or reed maintained at a potential difference with respect to two attracting plates. If the forces of attraction are equal and oppositely directed, the reed will be at rest. If, however, balance is upset by the introduction of new circuit element in a certain branch, mechanical vibrations will result, but may be nullified electrically. One of the novel features is the fact that the reed acts as a balance indicator with a relatively high a.c. voltage sensitivity.

Description and basic principle

The sensitive member in the present arrangement is a balanced tuned reed maintained in equilibrium under the action of two opposite alternating electrostatic forces. A slight change in one of these forces would set the reed into resonant vibration. It is possible, however, to restore balance by the adjustment of a potentiometer or a resistance whose value gives a measure of the disturbing force which can be made to result from the quantity under test.

The essential parts of the apparatus are shown in Fig. 1. D is a highly insulated thin aluminium reed ($2\text{ cm} \times 0.15\text{ cm} \times 0.01\text{ cm}$ approximately), clamped at one end O, and placed symmetrically between two parallel attracting plates of effective areas A_1 and A_2 , separated from D by distances d_1 and d_2 respectively. The total distance $d_1 + d_2$ between the two plates is about 1 mm, and is kept fixed by means of small

insulating separators of high grade, glued at the corners. The area of each plate is larger than the projected area of the reed, and the capacity between them, as well as any stray or distributed capacity, is made as small as possible.

The reed functions as a cantilever, and its length is trimmed that its natural transverse frequency is 100 c/s.

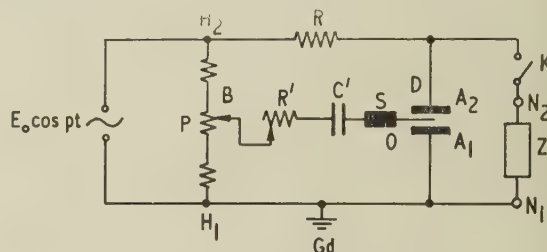


Fig. 1. Basic circuit of the electrostatic meter.

D is a metal reed pulled equally by the electrodes A_1 and A_2 . P is a $2\text{ M}\Omega$ ($1/2\text{ w}$) potential divider with a $50\text{ k}\Omega$ vernier central portion. Z is the load whose reactance and power factor are to be determined. R is a dropping resistor, and is normally of order of $1/100$ of the load reactance. The source is a 500 v 50 c/s mains. The circuit R'C' supplies the quadrature component of the balancing voltage. C' may be a fixed mica condenser of $0.01\text{ }\mu\text{F}$, and R' may vary between 0 and $10\text{ M}\Omega$.

which is double the mains frequency. The reed and the plates are all fixed on an ebonite (or preferably polystyrene) block screwed to a wooden base. Effective insulation and provision for small self-capacity are essential requirements for small power-loss measurement.

The potentials of the reed and of the attracting electrodes are supplied by means of a potential divider P whose total resistance R_P is $2\text{ M}\Omega$. The middle portion of P is a fine adjustment amounting to about 2% of R_P . A 50 c/s mains is connected to P through a variac and a mains isolating transformer (not shown in the figure), delivering an e.m.f. variable between 0 to about 500 v . Z is the component whose reactance and power loss are to be measured. R is a suitable dropping non-inductive resistance, and is arbitrarily chosen to be of the order of $1/100$ of the reactance of the load Z. The output indication may serve as a guide to the appropriate value of R. K is a key with a good quality insulation. R'C' is a circuit which can provide a voltage nearly in quadrature with the potentiometer voltage.

Balance is indicated by the absence of forced transverse vibrations in the reed. These vibrations may be detected electronically by connecting A_1 to earth via a capacitive responsive circuit with a visual indicator such as a cathode ray oscilloscope. A convenient vibration detector which when operated at low power imposes negligible h.f. voltage on A_1 has been described elsewhere by one of the present authors, and has been extensively employed in a number of measuring devices (Yousef 1953, 1954, 1955, 1958) based on

microvibration technique. Equality of the opposing forces on the reed can be normally secured with an accuracy to 10^{-4} . Despite the high sensitivity, the reed system is as robust as a galvanometer, since by virtue of the relatively high natural frequency and the adequate air damping, it is hardly affected by transient disturbances.

Suppose an e.m.f. $E_0 \cos pt$ is applied between H_1 and H_2 . If the load switch K is open, no voltage will be dropped on it provided the impedance between A_1 and A_2 is infinitely large. The opposing alternating electrostatic forces acting on the two faces of the reed when $R'C'$ is short-circuited will then be

$$F_1 = (A_1 V_{01}^2 \cos^2 pt) / 8\pi d_1^2 \quad (1)$$

and $F_2 = (A_2 V_{02}^2 \cos^2 pt) / 8\pi d_2^2$, (2) where p is the angular frequency of the source and V_{01} and V_{02} are respectively the amplitudes of the voltages on the two portions of the potentiometer.

Unless $F_1 = F_2$ there will be a resultant electrostatic force

$$F = \left(\frac{A_2 V_{02}^2}{d_2^2} - \frac{A_1 V_{01}^2}{d_1^2} \right) \frac{\cos 2pt + 1}{16\pi} \quad (3)$$

whose alternating component has an angular frequency $2p$.

As a matter of convenience we make $A_1 = A_2$, say by arranging the attracting plates approximately parallel to each other. It is also advisable to have the reed placed midway between the plates, so that $d_1 = d_2$ on the average. This is readily achieved by first making the resistances of the two portions of P equal, and then mechanically by adjusting by means of a screw motion the position of the reed support S which rests on a coach spring, not shown in Fig. 1) until the net force vanishes. In this case we may write $d_1 = d_2 = d$. If then V_{01} is different from V_{02} the net force would be

$$F = AE_0 v_0 (\cos 2pt + 1) / 16\pi d^2 \quad (4)$$

where $E_0 = V_{01} + V_{02}$, $v_0 = V_{02} - V_{01}$. It is implied that d remains constant, which is justified for small values of v_0 . It will be noted that the alternating as well as the steady component of the force is proportional to the voltage difference v_0 , both vanishing when $v_0 = 0$.

The resonant displacement amplitude a of the reed (regarded as a mechanical system with one degree of freedom) under the action of the alternating component of the exciting force is easily shown to be

$$a = \frac{AE_0 v_0}{16\pi d^2} \frac{\pi}{Mp^2 \Delta} \quad (5)$$

where M is the effective mass of the reed, $p' (= 2p)$ its natural transverse pulsance and Δ the logarithmic decrement of the motion which arises mainly from air damping due to the proximity of the plates A_1 and A_2 from the reed. The last equation determines the theoretical mechanical sensitivity for voltage (a/v_0).

The amplitude of the periodic capacity change corresponding to the displacement amplitude a is

$$c = \frac{A^2 E_0 v_0}{64\pi^2 d^4} \frac{\pi}{Mp^2 \Delta} \quad (6)$$

The various parameters involved in (6) are interrelated in a somewhat complicated way. However, since the effective mass M of the reed may be taken roughly as Ahp , where h is the thickness and ρ the density, it follows that

$$c = \frac{AE_0 v_0}{64\pi d^4} \frac{1}{hp^2 \rho \Delta} \quad (7)$$

As the damping is principally of aerodynamic nature, an increase in the area A would increase the damping in the same proportion. Further, too much reduction in d would necessitate the use of small E_0 (to prevent voltage breakdown) and would increase Δ greatly. Moreover, it would render the sensitivity seriously affected by changes of d due to strains or temperature fluctuations. Since p' has to be kept constant at double the mains frequency it appears that the capacity change per volt could be increased most conveniently by increasing E_0 (below the value corresponding to breakdown), decreasing the reed thickness (without seriously increasing fragility) and choosing for the reed a material of small density. Perhaps aluminium strips comply best with the requirements of high sensitivity combined with comparative ruggedness.

If we take $E_0 = 600$ v, $\Delta = 0.1$, $h = 0.01$ cm, and assume that a periodic capacity change of 10^{-4} pF, corresponding to a vibration amplitude of order 5×10^{-6} cm, could be observed, then a voltage change v_0 of about 0.01 v may be readily detected.

Theory and applications

In this section we shall give the theory of some obvious applications, namely the measurement of resistance, capacitance and power. All these applications depend on the disturbing action of the voltage created across the dropping resistor R by the current that flows in the unknown member Z when it is introduced into the circuit. This voltage is subtracted from the potential of the plate A_2 , and thus upsets the original balance. The in-phase component is balanced by the potentiometer P , and the quadrature component is balanced by varying the resistance R' of the arm $R'C'$.

The condition of balance is that the potential difference of the reed with respect to the two attracting plates is the same. This leads immediately to the relation

$$IR = 2V' + v \quad (8)$$

where I is the instantaneous load current which is also practically the current in R , v the difference between the instantaneous voltages on the two sections of the potentiometer P , and V' the instantaneous voltage on the circuit $R'C'$. This latter voltage arises from the small capacity between the reed support and the wiring to the attracting electrodes.

If V is the instantaneous load voltage, the instantaneous power dissipation is $V(2V' + v)/R$, whose average value is

$$W = V_0 V'_0 \cos \phi / R + V_0 v_0 \cos \beta / 2R \quad (9)$$

where V_0 , V'_0 , v_0 are respectively the maximum values of V , V' and v , ϕ the phase angle between the load current and the load voltage, and β the phase of the load voltage with respect to the source voltage. If R is smaller than 1/100 of the load reactance, then for power factors $\cos \phi$ between 0.9 and 0, $\cos \beta$ is practically equal to 1, while the load voltage does not differ from the source voltage by more than 2%, so that

$$W \simeq E_0 V'_0 \cos \phi / R + E_0 v_0 / 2R \quad (10)$$

For small power factors, much larger values of R may be safely used (cf. Table), so long as R remains sufficiently small compared with the loss resistance. Conversely, for large power factors, much smaller values of R have to be used.

The value of W given by (10) includes the intrinsic dissipation across the plates A_1 , A_2 . This is of the order of 200 μ w in the present circumstances, and is eliminated altogether by repeating the measurement with K open (i.e. external load excluded). It is generally possible to restore balance in the

second step with the load off by merely changing v_0 by Δv_0 , keeping R constant. This is because the contribution of the first term in (10) is always small—at low power factors because $\cos \phi$ is small, and at high power factors because V'_0 is small. The external power dissipation is thus

$$W = E_0 \Delta v_0 / 2R = 2E^2 f / R \quad (11)$$

where E is the root mean square voltage of the source, and f the fractional change of the potentiometer setting $= \Delta R_p / R_p$.

The loss tangent $\tan \delta$ and the parallel loss resistance S for a capacitive load of capacitance C are respectively given by

$$\tan \delta = 2f / pRC \quad (12)$$

and

$$S = R \cos \delta / 2f. \quad (13)$$

Very small power losses can be measured if R is made sufficiently large to give adequate reading accuracy, provided $C \tan \delta$ is not too small compared with $C_0 \tan \delta_0$, where C_0 is the self-capacity and δ_0 the intrinsic loss angle.

We note two special cases of Eqns (8) and (9), namely:

(a) *Purely resistive load.* In this case, balance is possible with $V' = 0$, i.e. $R'C'$ short-circuited. Hence, $I = v/R$ and the load resistance

$$S = VR/v \simeq R/2f \quad (14)$$

and the average power

$$W = V_0 v_0 / 2R \simeq 2E^2 f / R. \quad (15)$$

(b) *Purely capacitive load.* In this case, balance is possible with $v = 0$, $IR = 2V'$, i.e. by simply adjusting R' . The instantaneous power $VI = 2VV'/R$, whose average value is zero, since V and I (likewise V and V') are 90° out of phase.

If C is the load capacity then, for R much smaller than $1/pC$, it may be shown by circuit analysis that the voltage V' across the reed arm is almost in quadrature with the potentiometer voltage, and to a close approximation is given by

$$V' = \frac{1}{2} \mathcal{E} p C_{01} (1 - C_{02}/C_{01}) (R'^2 + 1/p^2 C'^2)^{1/2} \quad (16)$$

where $\mathcal{E}$ is the instantaneous voltage of the source, C_{01} the capacity between the reed and earth, C_{02} that shunting the reed and the high potential electrode. Thus V' arises from the inequality of C_{01} and C_{02} , and reverses sign when they are equal. Since $IR = 2V'$, we get

$$\mathcal{E} p CR = \mathcal{E} p C_{01} (1 - C_{02}/C_{01}) (R'^2 + 1/p^2 C'^2)^{1/2}. \quad (17)$$

Hence, when R' and C' are kept constant CR is constant.

The last relation suggests a method for measuring capacity depending on the sensitivity of the present arrangement to time constant. The procedure is to replace C by a known condenser C_1 , and keeping the impedance of the reed arm constant, adjust R to R_1 until balance is attained. In that case

$$CR = C_1 R_1. \quad (18)$$

The range of application may cover a factor of over 10^6 . It should be noted that C and C_1 include the self or input capacity, which is about 15 pF. Instead of using (18) we may

determine the unknown capacity from an empirical graphical relation between CR and R' when C' is maintained constant (Fig. 2). The input capacity C_0 may be also obtained from

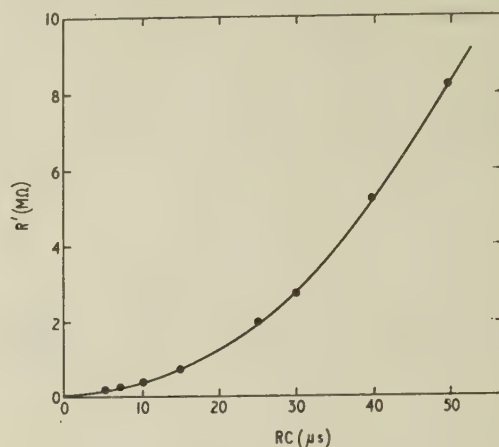


Fig. 2. Relation between RC and R' .

The curve may be used to determine C if R' is measured and R is known.

this curve by measuring R' corresponding to a known large value of R with the input terminals unconnected to an external load, i.e. shunted only by the input capacity C_0 . Then R' gives $C_0 R$, and consequently C_0 . A substitution method may be used advantageously for measuring a small capacity by replacing it with a standard variable air condenser. The accuracy is then to about 0.1 pF.

Typical results

Numerous experiments were made to test the performance of the tuned reed electrostatic meter. The outstanding features may be illustrated by using as a load an ideal air condenser of capacity $C_1 = 1000$ pF, shunted by a pure resistance S which may be varied between wide limits. Alternating current theory enables us to calculate the power factor $\cos \phi$ and whence the loss tangent $\tan \delta$ from the relation

$$\cos \phi = \sin \delta = 1 / (1 + p^2 C_1^2 S^2)^{1/2}. \quad (19)$$

The effective capacity is given by

$$C = C_1 \cos \delta. \quad (20)$$

We can measure C experimentally, say by observing the value of R' required to give balance, and then comparing the result with (20). Moreover, we can determine the power loss $W = 2E^2 f / R$ at the operating voltage and compare with the theoretical value which is practically equal to $E^2 p C \tan \delta$. In this way we can find the loss tangent (cf. Eqn (12)), and compare it with that deduced from (19).

Typical results using a shunted perfect condenser to represent a lossy condenser

(1) S (MΩ)	(2) R (kΩ)	(3) R' (MΩ)	(4) ΔR_F (Ω)	(5) W_{obs} (mw)	(6) W_{calc} (mw)	(7) $\tan \delta$ obs	(8) $\tan \delta$ calc	(9) C_{obs} (pF)	(10) C_{calc} (pF)	(11) S_{obs} (MΩ)
0.30	10	0.10	3500	87	87	9.98	10	110	100	0.27
1.0	20	0.15	6000	76	75	3.39	3.42	280	280	0.93
3.0	20	0.65	4500	56	56	1.0	1.0	710	707	2.9
10	50	7.2	5000	25	24	0.332	0.334	940	948	9.5
30	100	30	3000	7.4	7.4	0.100	0.099	990	995	30
100	300	90	3000	2.5	2.5	0.042	0.040	1000	1000	100
300	500	>100	1600	0.8	0.8	0.12	0.011	1000	1000	300

Finally, the parallel loss resistance S can be determined from (13) and compared with the known value of S .

The Table summarizes typical results taken at an operating voltage of 500 v (r.m.s.), 50 c/s. In the first column, the nominal value of the shunt resistance S is quoted. Column (4) gives ΔR_P , the potentiometer reading in ohms, from which $f = \Delta R_P/R_P$ is calculated. The experimental values of C in the last three rows may be obtained from smaller values of R if smaller values of R' are used. Comparison of columns (1) and (10), (5) and (6), (7) and (8) shows excellent agreement.

Conclusion

Although the Table is not meant to reveal the wide range

over which measurements may be conducted for C , S and W , yet the quoted range of $\tan \delta$ (a factor of 10^3) is wide enough to indicate the possibilities of the present method. It would appear that the present technique is particularly convenient for the determination of insulation resistance, and for the measurement of dielectric constant, loss tangent and electrical conductivity of liquids, solids and powders.

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Notes and Comments

Radio and Electronic Component Show

The Radio and Electronic Component Show will be held this year in the Grand Hall at Olympia, London, instead of at Grosvenor House, where it has been situated for the past 16 years. The Show opens on Tuesday, 30th May until Friday, 2nd June inclusive.

Industrial Finishes Exhibition

The first International Industrial Finishes Exhibition will be held at Earl's Court, London, from 8th–11th May 1961.

British Standards Institution

We have recently received notice of the following new publications of the British Standards Institution:

B.S. 3332: 1961—*White metal bearing alloy ingots*. Price 5s.
 B.S. 718: 1960—*Density hydrometers and specific gravity hydrometers*. Price 10s. B.S. 2634: Part 1: 1960—*Specification for roughness comparison specimens, ground flat and cylindrical types*. Price 4s. 6d. B.S. 1523: Section 2: 1960—*Glossary of terms used in automatic controlling and regulating systems, Process control*. Price 6s.

Rheological techniques

The British Society of Rheology and the Non-Destructive Testing Group of The Institute of Physics and The Physical Society will hold a joint meeting on this subject at Llandudno on the 21st and 22nd September 1961. The aim of the meeting will be to discuss rheological techniques in detail. Usually in the presentation of a paper discussion of experimental results is given at the expense of the description of the

techniques. It is intended that on this occasion the opposite will be true. The proceedings of the meeting will be published in special issues of *Laboratory Practice*. Contributions to the meeting are invited, and intending speakers should write to Dr. M. F. Culpin, F.Inst.P., 8 The Broadway, Pontypool, Monmouthshire, as soon as possible.

United Nations Conference on New Sources of Energy

The United Nations Conference on New Sources of Energy, which will examine practical problems and experience in the utilization of solar energy, wind power and geothermal energy, with especial reference to the problems of the less developed countries, will be held in Italy (probably in Rome) from 21st–31st August 1961.

The Conference aims at bringing together experts in the fields of the application of solar energy, wind power and geothermal energy, as well as those interested in energy development in general, to provide participants with up to date information on progress achieved, and to facilitate an exchange of views and experience relating to practical problems in utilizing these sources of energy. The Conference will focus attention on applications rather than on the discussion of scientific principles and basic research. Theoretical studies will be discussed only if they appear to be closely related to practical developments. The subject of costs will be emphasized and stress will be laid on the various needs for energy and on specific means for meeting those needs.

Attendance at the Conference will be by invitation only.

The Proceedings and a Report of the Conference will be published later, as United Nations Sales publications.

Requests for further information should be addressed to the Executive Secretary of the Conference, United Nations, New York.

A plastic capsule technique for the combustion calorimetry of volatile or chemically reactive compounds: the heat of combustion of polythene*

by H. MACKLE and R. G. MAYRICK, Department of Chemistry, The Queen's University, Belfast

MS. received 19th December 1960

Abstract

A technique for vacuum-forming polythene capsules for use in the combustion calorimetry of volatile or chemically reactive compounds is described. It has a number of advantages over the glass-ampoule method. Values for the heat of combustion of polythene are reported.

Introduction

A CONSIDERABLE number of compounds of current thermochemical interest are either volatile or chemically reactive or both. The precise calorimetry of such compounds is fraught with difficult technical problems. This is specially so for combustion heat studies in a bomb calorimeter. Here it is of vital importance (a) to prevent chemical change or contamination of the pure sample at any time prior to ignition, (b) to prevent evaporation of the sample during the weighing process or thereafter, (c) to ensure, in so far as may be compatible with (a) and (b) that the conditions for complete combustion of the sample are optimum.

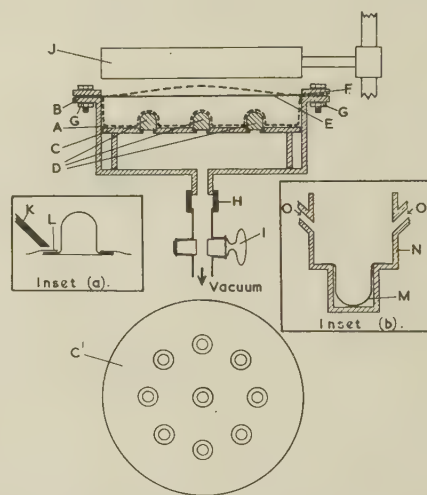
There have been several approaches to these problems, but the most efficacious and widely used has been to introduce the substance (usually a liquid) into glass ampoules of suitable size and then to seal these (Richards and Jesse 1910, Richards and Barry 1915, Prosen and Rossini 1941, Coops *et al.* 1947, Sunner 1949, Cox *et al.* 1954, Cox and Gundry 1958). Such sealed ampoules completely satisfy conditions (a) and (b) above, but they have a number of disadvantages. The technique of manufacturing and filling them requires considerable skill, and, even at best, is a hit-and-miss affair. They have to be strong enough to withstand the pressure (30–40 atm) of oxygen in the bomb without bursting and yet not so strong that they fail to break on ignition of the auxiliary burning substance. In general, they fail to satisfy condition (c) in that the risk of explosion and incomplete combustion is fairly high (Prosen and Rossini 1941, Coops *et al.* 1947, Sunner 1949). An ingenious way of minimizing these latter difficulties is due to Thompson (1953). Again, sealing of the ampoules is a very delicate operation since it is liable to cause a certain amount of decomposition of the sample. Finally, there is always the danger that the melting glass may occlude some intermediate products of the combustion though apparently this does not in general occur to any significant extent (Sunner 1949).

* This paper was originally read at a Symposium on experimental thermochemistry held in Innsbruck, Aug., 1959. In that month W. D. Good *et al.* (*J. Phys. Chem.*, 1959, **63**, 1133) reported the use of polyester bags in the combustion of liquid fluorine compounds.

The above considerations have led us to search for a straightforward and reliable alternative to the glass ampoule technique, and we believe we have found such in the following simple method for making closed polythene capsules of any desired size or shape.

Experimental procedure

The raw material for the method is polythene sheet 0.4 mm thick. This is heat-softened and vacuum-formed round suitable brass moulds with the aid of the set-up illustrated in the Figure. A is a cylindrical vacuum box fitted with



flange B. It is made of hard-drawn brass 1 mm thick. C is the brass platform carrying the nine moulds. It is a sliding fit for A and is shown in plan at C'. The moulds D fit snugly into 1 cm diameter grooves in the platform as indicated. Under each mould is a 0.5 cm diameter perforation. The polythene sheet E is clamped as a diaphragm on top of the box with the aid of a flat ring F and four wing-nuts, two of which are shown at G. H is a piece of pressure tubing and I is a glass tap. J is a 250 watt heating element. We actually use an Osram infra-red lamp (I.R.R. 48 P.F.). It is mounted on a swivel in the horizontal plane so that it may be swung quickly over and away from the polythene.

The actual procedure is as follows: When all is ready the tap I is closed and the pump started. J is then switched on and swung into position about 3 cm directly above the diaphragm. As a result of the expansion of the air in the box the polythene swells up slightly as it is heated. This

indicated by the dotted line in the figure, and is an important feature of the method. Without this slight pressure build-up the softening polythene would sag and foul the moulds before it is quite ready for vacuum-forming. The correct moment for removing the heat and applying the vacuum by opening tap I can be gauged easily by the eye: it is the moment at which the polythene has become quite transparent. On application of the vacuum, the polythene quickly 'forms' around the moulds as shown by the dotted line. The moulded sheet is then removed and the capsules cut out with a cork-borer of suitable (1.5 cm) diameter. Polythene lids are heat-sealed on the capsules by applying a soldering iron K to a 'fluon'-coated glass cloth L as indicated in the figure, set (a).

The simplest method of charging the capsules with liquids is to use a hypodermic syringe. A small puncture is first made in the lid and the liquid injected through a second puncture. It is quite easy with practice to heat-seal the punctures subsequently with a hot glass rod and a small known mass of molten polythene. For compounds which are susceptible to attack by atmospheric vapours or light the above operations may be performed readily in an inert atmosphere, such as dry nitrogen, in a dark room. The capsules may be charged with volatile or reactive solids with the aid of the apparatus shown in the Figure, inset (b). The capsule M without its lid is placed in the brass container N as shown. The system is swept out with dry nitrogen at the two inlets O. A suitable quantity of the solid sample is then transferred to M, the nitrogen counter-current being maintained the while. Finally, the lid is dropped into place and heat-sealed to the capsule as before.

results (cal g^{-1}) are given in the Table (1 cal = 4.1840 abs. joules).

In the Table the total heat quantity is the product of the corrected temperature rise and the calorimeter constant; iso-corr is the isothermal correction and Σ_{corr} is the sum of all other corrections to standard states; $\text{total}_{\text{corr}}$ is the corrected total heat quantity.

It will be clear from the Table that there is no significant difference in the combustion heats of the above two polythene samples. Very recently, however, we have determined $-\Delta U$ for a third sample and find its value to be $11080.6 \pm 1.4 \text{ cal g}^{-1}$, thus emphasizing the necessity to determine $-\Delta U$ for each new sheet. We have also carried out a series of tests to find whether there is any significant difference between $-\Delta U$ for a given sheet sample and $-\Delta U$ for a capsule of identical mass formed from the same sheet. There is not.

Discussion

The present technique has obvious advantages over those involving glass, including even some of the most recent and elegant (Sunner 1949, Fischel *et al.* 1957, Hubbard *et al.* 1958). Among these advantages are the following: (i) a large number of capsules almost identical in size, shape and weight can be made in a short space of time and without the need for any special skill; (ii) the size and shape of the capsules can be varied readily by changing the moulds; (iii) the capsules never burst before ignition as they are more than strong enough to withstand the pressure in the bomb; (iv) they are

Heat Quantities (cal)

Wt. g (vac.)	Total	Iso-corr + Σ corr	Total _{corr}	$-\Delta U(\text{cal g}^{-1})$
'Alkathene'				
0.263 664	-2902.13	-10.24	-2912.37	11 045.7
0.263 252	-2896.71	-10.48	-2907.19	11 043.4
0.269 522	-2967.15	-10.63	-2977.78	11 048.4
0.267 979	-2950.00	-10.52	-2960.52	11 047.6
0.266 591	-2935.10	-10.55	-2945.65	11 049.3
0.265 371	-2921.54	-10.55	-2932.09	11 049.0
0.267 437	-2943.22	-10.64	-2953.86	11 045.1
			average	11 046.9 $\pm$ 1.5
'Aerotherene'				
0.285 303	-3139.87	-11.70	-3151.57	11 046.4
0.282 304	-3107.13	-11.51	-3118.64	11 047.1
0.290 464	-3196.31	-11.98	-3208.29	11 045.4
0.285 702	-3144.36	-11.75	-3156.11	11 046.9
0.281 534	-3097.39	-11.73	-3109.12	11 043.5
0.286 234	-3148.94	-11.88	-3160.82	11 042.8
			average	11 045.3 $\pm$ 1.5

If the application of the present technique is to be reliable it is necessary to determine precisely in each instance the heat of combustion of the actual polythene sheet in use. This is because the heat of combustion of polythene may well vary from one batch to another due to different degrees of cross-linking, surface oxidation, etc. We have, so far, used two different batches of polythene (I.C.I. 'Alkathene' and 'Aerotherene' Ltd.) and determined the combustion heats ΔU of these under standard conditions with the apparatus described in an earlier paper (Keith and Mackle 1958). The

readily combustible and thus serve the purpose of an auxiliary burning substance, although they do not invariably eliminate the need for the latter; (v) the fuse wire can be fixed at the neck of the capsules so that they have prolonged burning contact with the sample. The conditions for complete combustion are thereby enhanced; (vi) polythene is resistant to attack by most chemicals at ordinary temperatures. The need, except in very special circumstances, for such as quartz ampoules (Scott *et al.* 1956) is thereby removed.

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Acknowledgments

We thank Mr. M. A. H. Lanyon, I.C.I. Ltd. (Plastics Division) for valuable advice on the vacuum-forming procedure. R.G.M. is grateful to the Ministry of Education, Northern Ireland, for a research maintenance grant.

New books

Induction-type integrating meters. By G. F. SHOTTER and G. F. TAGG. (London: Pitmans, 1960.) Pp. vii + 214. Price 63s.

The determination of gases in metals. Report of a symposium organized by The Society for Analytical Chemistry in conjunction with The Iron and Steel Institute and The Institute of Metals. (London: The Iron and Steel Institute, 1960.) Pp. viii + 308. Price £3 3s.

Tables related to radiation emerging from a planetary atmosphere with Rayleigh scattering. By K. L. COULSON, J. V. DAVE and Z. SEKERA. (Berkeley and Los Angeles: University of California Press, 1960.) Pp. x + 548. Price 116s.

The problem of radiative transfer in a sunlit planetary atmosphere is to determine the intensity and polarization of the

diffuse radiation emerging from the top and the bottom of the atmosphere. The exact solution of this problem has been arrived at by S. Chandrasekhar for the case of a plane-parallel atmosphere with Rayleigh scattering. The present book explains Chandrasekhar's methods, provides tables and lists the parameters required to determine the radiative

The electro-erosion machining of metals. By A. L. LIVSHITS. (London: Butterworths, 1960.) Pp. xi + 115. Price 36s.

The information given in this book constitutes a complete and up to date description of the state of the technique and technology and industrial uses of electro-erosion machining. Greatest importance has been placed on the electro-pulse methods which have better technical and cost characteristics and a wider field of application than the electro-spark. The author introduces a number of definitions and classifications which will be of use in the further working out of the basic ideas in this new field of electrotechnology.

A simple and cheap thermal conductivity apparatus

by D. W. STOPS, Ph.D., A.R.C.S., A.M.I.E.E., A.Inst.P., Bell's Asbestos and Engineering Limited, Slough, Bucks.

MS. received 19th January 1961

The guarded hot-plate apparatus is the type most widely used for the measurements of the thermal conductivities of insulating materials. This is ideally a simple device but, in practice, there are many problems of construction; it is cumbersome, slow to come to equilibrium and difficult or tedious to control. The inhomogeneous nature of many industrial insulating materials and the indeterminacy in locating temperature sensing elements due to the uncertainties of the effects of thermal contacts renders high accuracy of thermal conductivity measurements generally beyond reach, even in a perfectly balanced system. For rapid and frequent tests of materials, an unguarded system may be used to give a similar order of accuracy, provided certain conditions are satisfied. The overall requirements are that heat shall be produced uniformly over each area of the hot plate; the temperature sensing elements should be at the centre of the system where the heat flux is normal to the planes of the heater and cold plates and, finally, the lateral thermal conductance of the system shall be small compared with the conductance normal to the plates.

A thin plate heater system has been described by Hager (1960) where the heater is an 8 in. $\times$ 8 in. square of stainless steel foil, and samples of insulating material $\frac{1}{2}$ in. thick are secured on both sides of this by tape. Thermocouples are similarly secured on to the faces of the specimens and the whole system is enclosed in a plastic bag for insertion in a constant temperature bath. This arrangement has given conductivity values in agreement with those obtained by other means. This system, whilst much simpler to form and operate than the standard equipments, introduces certain difficulties in construction and operation due to the nature and the very low resistance of the heater element. A modification to this apparatus is proposed which uses electrical conducting paper as the heater element and hot plate. Electrical contact is made by painting strips of silver dispersion on the two opposite edges of the paper. To facilitate construction, two pieces of paper are stuck back to back with fine wire thermocouples located between them. Copper foil is folded to contact the silver strips and slightly crimped to make good electrical connections. Potential and current leads are soldered to these strips. Two squares of flat aluminium sheet cut to the same size as the heater, each with a thermocouple attached to its centre by adhesive tape, are used as the cold plates. Two similar samples of material to be tested are placed either side of the heater and the whole is sandwiched between the two aluminium plates and secured by rubber bands. Such an apparatus is made very quickly and cheaply.

The small thermal capacity of the heating element contributes to the rapidity with which the system comes into thermal equilibrium once power is applied. The low thermal conductivity of the paper minimizes the lateral losses which can give rise to considerable errors in parallel plates systems (Woodside and Wilson 1957, Woodside 1957).

The results below refer to an apparatus using an 8 in. $\times$ 8 in. heater and cold plates. The Teledeltos paper (by Standard Telephones and Cables Ltd.) of 0.0035 in. thickness had a resistance of about 500 Ω per square, resulting in a heater

resistance of approximately 250 Ω . Three 40 s.w.g. copper-constantan thermocouples were located between the resistance papers, one in the centre and the other two $\frac{1}{2}$ in. either side. These were used to give an indication of uniformity of temperature over the central portion of the system. Similar couples were secured to the inner faces of the cold plates by sticky tape. The relatively high resistance of the heater element allowed facile measurements on power dissipation and minimized any effects of imperfect electrical contacts.

Results of thermal conductivity test on samples of flexible polyurethane foam 8 in. $\times$ 8 in. $\times$ $\frac{1}{2}$ in. thick at 2 lb/ft³ density.

Heater input	2.5 w at 25 v—measured with Cambridge Instrument Co. a.c. test set.
Temperatures ($^{\circ}$ F)	ambient 52; hot plate 74; cold plates 57—measured with Cambridge Instrument Co. workshop potentiometer.
Calculated k value	0.27 Btu ft ⁻² h ⁻¹ (deg F/in.) ⁻¹ .

The steady state condition was reached within 30 minutes, and results did not differ when the samples were cut 12 in. square to provide their own edge insulation. However, it is evident that thicker samples are best used oversize to reduce edge losses. With the apparatus, tests on 9 in. square cork-board of 1 in. thickness and 8 lb/ft³ density, gave a k value of 0.34 Btu ft⁻² h⁻¹ (deg F/in.)⁻¹ at a mean temperature of 69 $^{\circ}$ F, but now the steady state condition was reached in 3 hours and there were small discrepancies (<1%) in the hot plate thermocouple readings.

In measurements near ambient temperature there appears to be little advantage in force cooling or controlling the temperatures of the cold plates. When little power is dissipated, the two cold plates can differ only a little in temperature under the worst ambient conditions. If control or changes in mean temperature are desired, then the plastic bag method of Hager (1960) can be used.

It may be argued that Teledeltos paper is subject to variations in resistance over its area and that the negative temperature coefficient of the graphite will, in any case, cause a disproportionate power dissipation at the edges of the heater compared with the centre where the temperature measurements are made. However, samples of paper can easily be tested for equality of resistance and, provided only small temperature differences are established, the effects of small local non-uniformities are negligible compared with errors which can arise in more elaborate systems.

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Electropolishing techniques for the preparation of zirconium and Zircaloy-2 specimens for transmission electron microscopy

by J. L. WHITTON, Atomic Energy of Canada Ltd., Chalk River, Ontario

MS. received 21st December 1960

Zirconium and its alloys are suitable structural and sheathing materials for a nuclear reactor because of their low thermal neutron capture cross section. A great deal of information has been gathered concerning the effects of neutron irradiation on the mechanical properties of these materials. To supplement this information, a study of the dislocation arrangements in the irradiated and unirradiated states was initiated, and hence a method of preparing thin foils suitable for transmission electron microscopy was required.

Kelly and Nutting (1958–1959) have recently classified the several methods used to prepare thin foils. Of these, electropolishing is the most successful and the techniques of Tomlinson (1958) and Bollmann (1956), the latter adapted and extended by Boswell and Smith (1958), seem to give the most consistent results. The size of the specimen, in this case limited by available irradiation facilities to $\frac{3}{8}$ in. width, ruled out the latter two techniques as they require a specimen of about $\frac{3}{4}$ in. diameter. However, good polishing conditions could not be achieved by the Tomlinson technique so the Boswell and Smith technique was modified and found to give extremely good results.

The modified Boswell and Smith apparatus is shown in Fig. 1. The foil, 1 in. $\times$ $\frac{3}{8}$ in. $\times$ 0.001 in. to 0.003 in.,

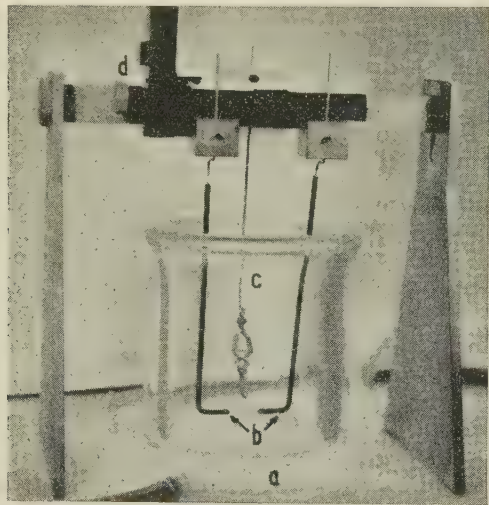


Fig. 1. Apparatus for preparing thin foils.

a, double-walled water-cooled glass vessel; b, insulated cathodes; c, anode spring clip; d, vertical cathode adjustment control.

insulated round the edges with polystyrene in trichlorethylene, is mounted in the spring clip c as the anode. The cathodes b are mounted separately from the anode and can be moved vertically without altering the position of one cathode relative to the other. The electropolishing sequence is as follows:

The cathodes are positioned close to and near to the bottom of the foil, until a small hole appears (Fig. 2(a)). The cathodes are then moved quickly to a position near the top of the foil and left until another hole appears (Fig. 2(b)). They are then

brought to the centre of the foil and moved about 1 cm apart. Polishing is continued until the holes enlarge and just meet (Fig. 2(c)). The time required for the complete sequence between one and three minutes depending on the thickness

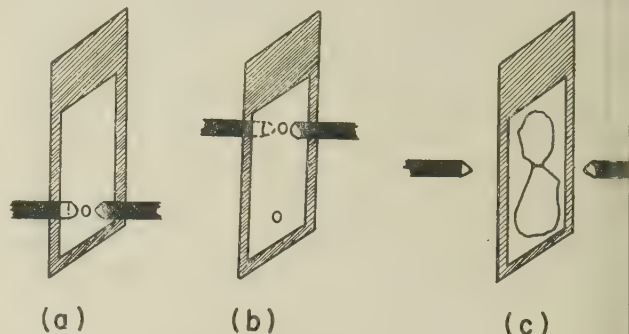


Fig. 2. Electropolishing sequence during preparation of thin foils.

of the starting foil. The foil is then removed quickly, rinsed with ethyl alcohol and dried between filter paper. Suitable specimens are cut from the regions near the junction of the two holes. Thinner sections can be obtained by rapidly switching the current off and on several times before removal of the foil from the electrolyte (Tomlinson 1958).

The polishing conditions for zirconium and Zircaloy are as follows:—

Electrolyte	40 ml. HClO_4 (72%)	: 160 ml. $\text{C}_2\text{H}_5\text{OH}$
Cathodes	Stainless steel	0.040 in. diam.
Voltage	20–22 v	
Current	0.6 A	
Temperature	< 25° C	



Fig. 3. Transmission electron micrograph of zirconium showing dislocation interactions. $\times 28\,500$

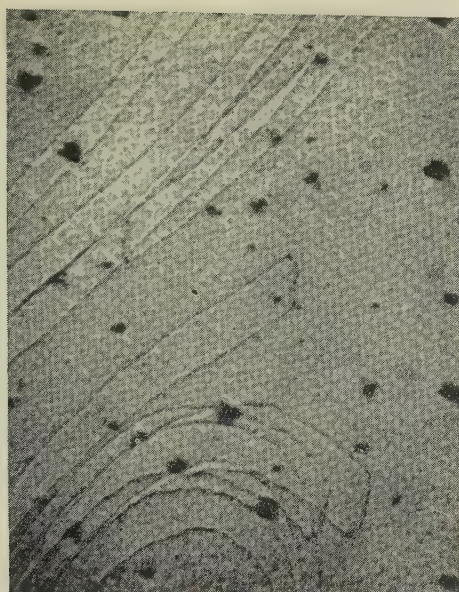


Fig. 4. Transmission electron micrograph of Zircaloy-2 showing non-crystallographic cross slip. $\times 33\,000$

The electrolyte should be stirred during the electropolishing.

This technique has the advantage of greater control than those mentioned, because only two holes need be watched compared with the many in the Bollmann method and the rate of growth of the holes can be adjusted by upward or downward movement of the cathodes.

The foils were examined in a Siemens Elmiskop I electron microscope operated at a voltage of 80 or 100 kv. Typical micrographs are shown in Figs. 3 and 4.

Suitable thin foils of aluminium, iron and stainless steel, both in the irradiated and unirradiated conditions, have been obtained using this technique with the electrolytes recommended by Boswell and Smith (1958).

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A method for sealing a watch jewel into hard glass

by G. P. BURN and P. J. TOSH, Department of Clinical Biochemistry, Radcliffe Infirmary, Oxford

MS. received 9th January 1961

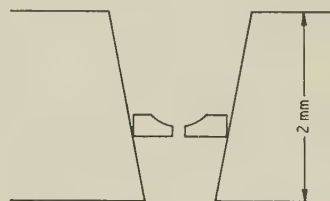
It is often desirable to have small holes of known size in glass apparatus. We employ them in our electronic counter for red blood cells (1961).

Watch jewels can be obtained with pivot holes of various sizes, say from 0.25 to 0.07 mm diameter. A jewel with a pivot hole of 0.1 mm diameter has an overall diameter of 1.0 mm and a thickness of 0.25 mm. The depth of the pivot hole is only about 0.1 mm.

The jewel is sealed into the side of a Pyrex tube whose wall thickness is 2 mm. For a jewel of 1 mm diameter a hole of 0.7 mm diameter is first ground out with 400 grit size carborundum, mixed to a creamy consistency with water and retained with a Plasticene ring. The drill is made from 6 mm silver steel turned down to 0.7 mm in steps, with a flat face. The glass tube is supported on Vee blocks or waxed to a base. The drill rotating at 500 rev/min is started with short light touches. Care is taken that the carborundum does the cutting, and that a large 'burst through' into the lumen of the tube is avoided.

The hole is now ground out further with a tapered tool so that the jewel can pass about two-thirds of the way through

the wall of the tube (see Figure). A suitable taper was found at the point of a steel scriber.



Jewel placed in tapered hole.

The hole is cleaned, the jewel inserted and the tube warmed up all over in a soft flame. With a small hand lamp, using coal gas and oxygen, the jewel and surrounding glass are heated so that the glass softens and runs over the edges of the jewel. A blowing rubber and swivel is attached so that when the jewel is held by the glass it can be blown out a little. Annealing is done in the flame of the bench lamp.

BURN, G. P., and TOSH, P. J., 1961, *Electronic Engng*, **33**, in the press.

A.C. type ear oximeter

Goldie (1942) and Paul (1953, 1955) have published several papers on the a.c. oximeter employing a photocell amplifier system. In our experience their method, which depends on the linear relationship between the amplified voltage output from a selenium barrier layer photocell and the logarithm of the linear light intensity, is invalid for oximetry, as is indicated by the following experiment.

A light source modulated at 60 c/s was made to irradiate a selenium barrier layer photocell whose output was proportional to the logarithm of the received light intensity (Fig. 1).

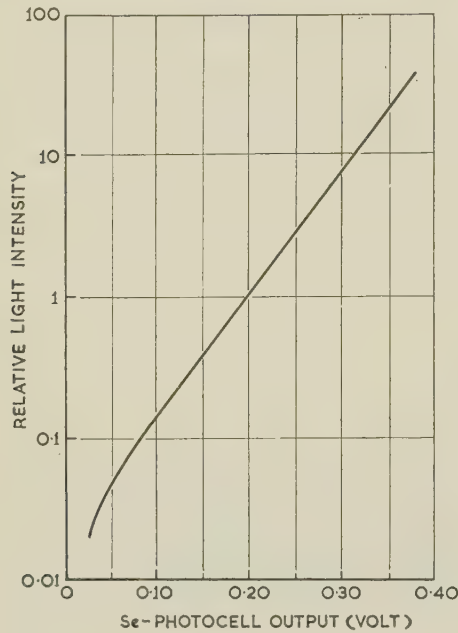


Fig. 1. Relationship between relative changes of intensity of incident light and the output voltages of Se photocell.

The output of the photocell was fed to an a.c. amplifier sensitive only to the a.c. component. A filter inserted between the light source and the photocell to reduce the input light intensity will not alter the output of the amplifier, since it is a function of the degree of modulation only, and nearly proportional to it.

Figure 2 shows the experimental layout. The output, amplified by a d.c. amplifier, was recorded on a Duddell type

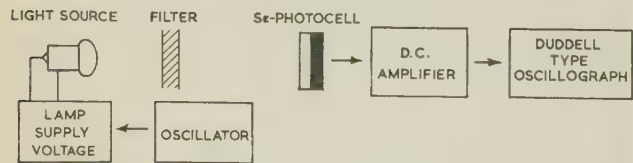


Fig. 2. Block diagram of the experimental layout.

oscilloscope. The trace on the oscilloscope was photographed under successive interruption of light with and without a filter (9% transmission), and the result is shown in Fig. 3. Note that the amplitude of the a.c. component is independent of the presence of the filter.

The light from the source was then divided into two parts by a half mirror; one part was detected by an RCA-931 photomultiplier tube whose output voltage was linear

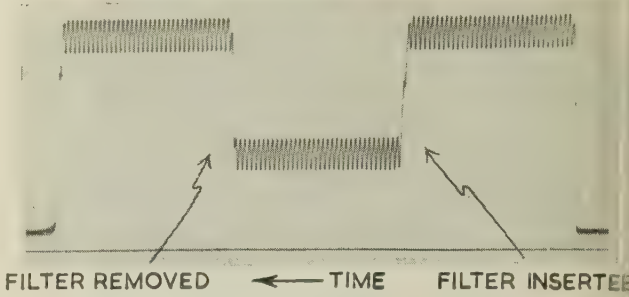


Fig. 3.

proportional to the incident light, and the other by a selenium barrier layer photocell whose output was proportional to the logarithm of the incident light. The output from the two detectors were fed into d.c. amplifiers (curves Id and Ia of Fig. 4). The results when a.c. amplifiers were employed instead of d.c. amplifiers are shown by curves Ia and IIa.

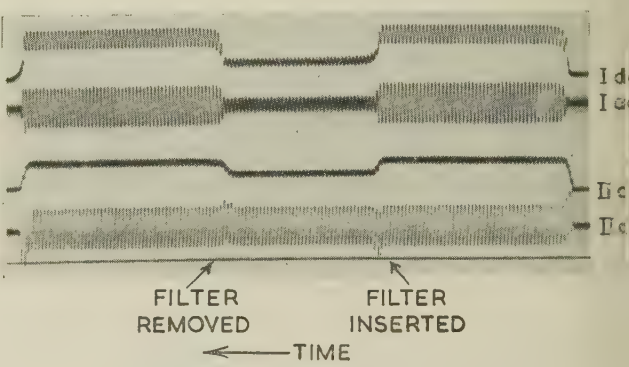
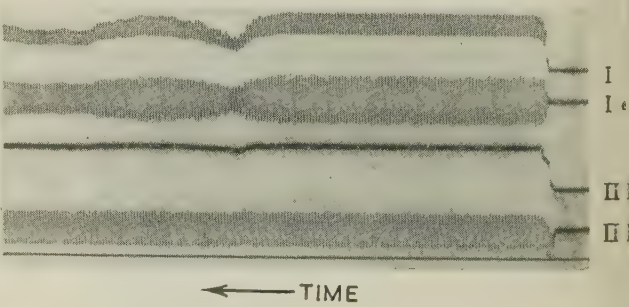


Fig. 4.

The filter was then replaced by the smoke of a cigarette and the result is seen in Fig. 5. It is to be noted that curve IIa of Fig. 5 is practically independent of the degree



- Id: output voltage of d.c. amplifier (photomultiplier).
- Ia: output voltage of a.c. amplifier (photomultiplier).
- IId: output voltage of d.c. amplifier (Se photocell).
- IIa: output voltage of a.c. amplifier (Se photocell).

Fig. 5.

sorption of light suffered between the light source and the detector provided the degree of modulation is not altered. This experiment shows that the a.c. output voltage of the detector, when it is made proportional to the logarithm of the incident light intensity, is not sensitive to any intermediate disturbance; thus it will detect only the degree of modulation of the light regardless of any disturbance inserted along the path of the light. This indicates that further thought should be given in order to attain a satisfactory measuring device which uses the a.c. oximeter to estimate the degree of oxygen saturation of human arterial blood.

An a.c. ear oximeter employing two light sources, an inter-

ference filter and a logarithmic detector has been constructed, the detail of which will be published shortly.

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15th June 1960

GOLDIE, E. A. G., 1942, *J. Sci. Instrum.*, **19**, 23.

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New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep her informed of their new or improved products. The Institute of Physics and The Physical Society assumes no responsibility for the statements given below; information for these has been taken from literature supplied.

Ribbon feeder connector. Belling and Lee Ltd., Great Cambridge Road, Enfield, Middlesex.

Ribbon feeder is a flat flexible insulating ribbon containing a number of parallel copper foil strip conductors, the primary purpose of which is the interconnection between printed circuits. This connector is designed to enable two of these to be joined so that no strain is placed on the ribbons, and an extra locking device is available. It is claimed that the connector contact resistance is less than 5×10^{-3} ohm, its insulation resistance is greater than 10^{12} ohms, the capacity, 1 pf between the ways (conductors) and the insertion and withdrawal force, 8–10 oz per contact. Connectors are available for 8 to 18 ways.

Multi-specimen creep testing machine. The United Steel Companies Ltd., The Mount, Broomhill, Sheffield.

This machine is intended for testing the steel parts of boilers, turbines, and certain chemical plants. It is designed to carry out four high-sensitivity tests or twelve fracture tests on the machine. There are four loading systems, each of which tests for one high-sensitivity test or three stress-to-fracture tests in series. There is a single furnace and temperature controller for all the four systems.

The advantage is claimed of the concentration of a number of testing stations within a comparatively small space, its floor space being about one square yard and several machines can be arranged in a row at 4 ft spacings; guards are provided to prevent contact with the loading weights. The complete unit consists of the machine itself, the furnace, a fused silica tube with wire wound in sections for resistance heating, and a

control panel incorporating the thermometer control, together with a lifting jack. The machine can be used for loads up to three tons on a specimen.

Automatic sample-changer for well-crystal scintillation counter.

Nuclear Chicago Corporation, 333 East Howard Avenue, Des Plaines, Illinois, U.S.A.

This is a precision electro-mechanical instrument which holds a large number of test tubes containing γ -ray-emitting liquid or solid samples and lowers them one by one into the well crystal of a shielded scintillation counter. The instrument is used in conjunction with a scaler (or scaler and spectrometer), a printing timer, and a well-type scintillation counter. Operation is completely automatic.

The capacity is 49 test tubes. In operation, one of the test tubes is lowered into position and the scaler is activated to count to a pre-set number. At the end of the count, the printing timer records the length of time required to reach the preset count. After the count the sample is raised into its place in the ring, and the scaler registers the next sample. The sequence is repeated until all the samples have been counted, and then if required the machine can be arranged to stop or repeat.

The instrument is arranged for lights to indicate when a count is in progress, and the dimensions are 32 in. high, 22½ in. wide and 32 in. deep.

VDR-105 secondary standard voltage divider. Julie Research Laboratories Inc., New York, N.Y.

The VDR-105 is a five-decade Kelvin–Varley divider, with accuracy, resolution and long-term stability rated at 0.001%. This performance is maintained over the full laboratory temperature range of 20°C to 30°C without correction. Because of its reduced size and cost it can conveniently be used in laboratory and production applications where primary standard accuracy is not necessary. Precision encapsulated resistors and the use of stabilization processes minimize the influences of external fields and self-heating.

The circuit employed in these instruments contains no potentiometer or verniers—all decades are switched over the entire hundred thousand-to-one range.

Digital frequency meter, Type SA.505. Rcal Instruments Limited, Bracknell, Berkshire.

The SA.505 uses transistor techniques in a compact, self-contained instrument and is said to be suited to all laboratory applications in the fields of frequency, period and time interval measurement. A seven digit in-line projection display is incorporated which is arranged to display continuously. Facilities include direct frequency measurement of sinewave and pulse signals in the range 0–10 Mc/s, time interval measurement between two successive positive or negative going pulses in the range 0.1 μ s to 10^4 seconds. Period measurement can also be made over 1, 10 and 100 cycles of the unknown frequency with an accuracy of up to 1 part in 10^6 . The accuracy of frequency measurement is ± 1 count $\pm$ the stability of the internal crystal which is 1 part in 10^7 , provision being made for operation from an external frequency standard of 100 kc/s or 1 Mc/s. Digital outputs are available from the instrument in the form of relay contact closures enabling a remote readout to be operated directly.

Portable industrial X-ray units. Manufactured by C.H.F. Muller, Hamburg; distributed in U.K. by Research and Control Instruments Ltd., 207 Kings Cross Road, London, W.C.1.

The Muller x-ray units Models K and L are claimed to give consistent radiographs through automatic application of voltage to the x-ray tube. Voltage and time of exposure are pre-selected and operation is automatic after the 'Exposure' button is pressed, the voltage being applied in two stages which provide full electrical safeguards. Model K weighs 55 lbs and has a maximum output of 140 kv 5 ma with a 1.2 mm focal spot; Model L weighs 84 lb and has a maximum output of 200 kv 5 ma with a 1.6 mm focal spot. One control box, weighing 55 lb, is suitable for either unit.

It is claimed that both units have excellent duty cycles, achieved by means of an internal heat exchanger with forced circulation of the insulating oil. For continuous running an external water-cooling attachment is easily fitted. The control box incorporates both voltage and thermal overload protection, and a blinker device for the connection of a high-tension warning lamp.

Continuous duty air sampler. Gelman Instrument Co., Chelsea, Michigan, U.S.A.

This air sampler, which is designed for 24 hour usage, draws up to 16 litres/min of air through a filter paper. Consisting of a vacuum pump, flowmeter and filter holder built into a carrying case, it measures 9 in. $\times$ 5 in. $\times$ 4½ in., and weighs 8 lb.

The filter holder can be connected to or disconnected from the sampler quickly, and this makes it possible to avoid contamination by loading filter holders in the laboratory and then making changes in the field.

High voltage pulse generator. Lunartron Electronics Ltd., Leighton Road, Northall, Dunstable, Beds.

The Lunartron High Voltage Pulse Generator is designed as a trigger unit to promote discharge in a spark gap light source for Schlieren or Shadowgraph optical systems, but it

can also be used for triggering xenon-filled flash tubes and for pulse firing suitable mercury vapour lamps. It provides either positive or negative pulses of approximately 18 ns under open circuit conditions, which rise to peak amplitude in 30 μ sec, and it is suitable for repetition firing up to 20 Hz. The unit may be triggered in one of three ways: by pressing a spring-loaded switch mounted on the front panel; by supplying a positive pulse or square wave to the input; or by short-circuiting the input with an external switch.

Automatic tape degausser. Consolidated Electrodynamics Corporation, 360 Sierra Madre Villa, Pasadena, California, U.S.A.

The TD-2903 Automatic Tape Degausser is designed to erase data signals from magnetic tape wound on reels. A reel of 1 in. wide tape recorded at saturation level is erased to a nominal 90 db below saturation level. Consistently uniform degaussing is achieved through automatic time cycling of the reels in the erasing field. When the starting button is pressed, the reel moves slowly into the erasing field, rotates several times through 360°, and slowly withdraws to its original position, when the unit switches itself off. The cycle is completed in about 110 seconds. Heavy shielding is incorporated to prevent the erasing field affecting other tape system components.

The unit, which measures 15 in. high by 16 in. wide by 22 in. deep and weighs 90 lb, can be used with CECS NARTB reel-hubs, and with reels from 7 in. to 14 in. diameter. Tape widths from ¼ in. to 2 in. are accommodated. Hub adaptors are available for reels having other dimensions, such as IBM reels.

Single and double pulse generator. Solartron Laboratory Instruments Ltd., Cox Lane, Chessington, Surrey.

The GO 1005 decade pulse generator provides positive or negative going, single or double rectangular pulses of up to 100 volts amplitude at repetition rates from 10 c/s to 1 Mc/s when triggered internally, and to 2 Mc/s when triggered externally. Coarse and fine adjustments of pulse duration, repetition time and signal delay are obtained by means of three sets of concentric decade controls, and there is a built-in amplitude monitoring meter.

The rectangular pulse duration, and the signal delay time relative to a 10 v pre-pulse output, are variable over the range 250 ns to 100 ms. In the double-pulse mode of operation the leading edge of the first rectangular pulse coincides with the pre-pulse, and the leading edge of the second identical rectangular pulse occurs after the set signal delay. A delayed pre-pulse, which is also available approximately 250 ns after the pre-pulse, provides a trigger output which may be made to coincide exactly with the leading edge of the main rectangular pulse.

Wide-range R-C oscillator. Solartron Laboratory Instruments Ltd., Cox Lane, Chessington, Surrey.

The portable CO 1004 oscillator provides symmetrical low distortion sinewave outputs, of 0° and 180° phase relationship, continuously variable over the frequency range 10 c/s to 1 Mc/s. A 'balance' control is incorporated to obtain perfect symmetry about earth at low frequencies. The frequency is accurate to within $\pm 2.5\%$, and the frequency stability is such that the set frequency is held to within $\pm 0.2\%$ over an eight-hour period. Total harmonic distortion is less than 1% between 20 c/s and 200 kc/s, and 1

an 2% outside these limits. The output level per phase is continuously variable up to 20 v r.m.s. into loads greater than 20 k Ω , and 10 v r.m.s. into 600 Ω . Amplitude stability over the entire frequency range is to better than $\pm 5\%$.

Direct reading inductance and capacitance meter. Solartron Laboratory Instruments Ltd., Cox Lane, Chessington, Surrey.

The MM 906 L-C meter provides continuous readings of inductance and capacitance from 0 to 300 μH and 0 to 300 pF respectively, in five ranges with accuracy to $\pm 3\%$. On the lowest ranges full scale deflection is 3 μH and 3 pF. The noted accuracy is maintained with resistance loads of 20 k Ω and 10 Ω series on 'Inductance' setting, and 0.1 M Ω and 10 Ω series on 'Capacitance' setting. A 'guard voltage', sufficient to drive 200 pF, enables the elimination of effects due to unwanted capacitances.

Radiation shielding windows. Pilkington Brothers Ltd., Chance-Pilkington Optical Works, Glascoed Road, St. Asaph, Flintshire.

Chance-Pilkington are manufacturing windows for shielding against atomic radiation made from glasses of densities ranging from 2.67 g/cm³ to 6.1 g/cm³ (glass of density of 6.1 g/cm³ is available only in pieces up to 500 in³ in volume). The windows are made in three basic designs; in one design the window must be inserted from the active side of the main shielding wall and a second design allows it to be inserted from either side of the wall. The third type is of 'umb-bell' cross section and provides the maximum angle of view for a given weight of glass and for given shielding. The latter kind of window is the most economical design. The use of the window is dependent upon movement of the observer and it is often advisable to use this shape of cross section in the horizontal plane only.

Particle size analyser. Carl Zeiss, Oberkochen, Germany.

For fully automatic instruments for particle size analysis a reliable result can be obtained only if all the particles be separated from one another and only if they do not deviate greatly from a circular shape. Moreover the photograph of the particles used in the analysis must be of an adequately high contrast and there must be no foreign particles in the picture. Endter and Gebauer (1956) have designed a semi-automatic instrument which is now manufactured by Carl Zeiss as the Particle Size Analyser Model TGZ3 which only requires that the particles imaged in the photograph should be cognizable to the eye as to dimensions and kind; the particles may overlap, be in contact or even superimposed. Mixtures of different kinds of particles may be evaluated separately for each component.

The photograph of the particles is laid on a Perspex plate and the image of an illuminated iris diaphragm formed upon it. The diaphragm is adjusted until the circular light spot is equal in area to that of the particle. Experience has shown that this can be done readily. The different diameters of the diaphragm are correlated via a commutator with a number of counters, each counter covering a certain range of diameters. When the diaphragm and particle areas have been equalized a foot switch is depressed which activates the counter and a punch marks the photograph. The photograph is then moved to the next particle. Forty-eight counters are provided so that particle sizes are divided into forty-eight categories. In addition to these counters another

counter is provided which registers the total number of particles counted.

ENDTER, F., and GEBAUER, H., 1956, *Optik*, **13**, 97.

Transistorized 10 Mc/s counter timer Model 365. Transistor Specialities Inc., Terminal Drive, Plainview, L.I., New York.

A completely transistorized 10 Mc/s counter-timer performs the following measurements: totals of random events over any of nine time intervals from 0.1 microsecond to 100 seconds, and any multiple of 10 seconds (extended time base); straight counts with capacity of 9 999 999; frequency from 10^{-7} to 10 seconds; time interval from 0.1 microsecond to 100 seconds, in nine ranges in decade steps; period measurements from 0.1 microsecond to 10^8 seconds.

The range of the instrument as a counter is 1 c/s to 10 Mc/s (sine waves) and $0-10^6$ pulses per second without heterodyning or use of plug in units. Exceptional stability is obtained by use of a temperature controlled crystal oven, resulting in an overall stability of 5 parts in 10^8 per week and an accuracy to 1 count plus or minus crystal stability.

Resolution is 0.1 microsecond and sensitivity 85 millivolts r.m.s. Input impedance one megohm shunted by 40 picofarads.

The in-line digital readout is legible in any ambient light condition and employs long life (5000 hours) tubes.

The instruments internal crystal-controlled clock is brought out on the front panel as secondary frequency standard with an absolute stability of 0.5 parts in 10^7 per week. In addition to the 10 Mc/s crystal-frequency sine wave a 1 Mc/s sine wave and square waves at 100 kc/s, 10 kc/s, 100 c/s, 1 c/s and 0.1 c/s are available.

The 365-R (a 19 in. rack mounted version) is also available. Both models having a 1 year guarantee.

Weight is 26 lb, power consumption 49 watt at 115/230v a.c. 50-400 c/s.

Paramagnetic oxygen detector. Cambridge Instrument Co. Ltd., 13 Grosvenor Place, London, S.W.1.

In this detector, advantage is taken of the strong paramagnetic property of oxygen which distinguishes it from most other common gases, which are diamagnetic. Two similar heated filaments are mounted in cavities in a metal block and each is open to a stream of gas mixture to be analysed. One of the filaments is located in a strong magnetic field and each forms one arm of a bridge network so that differences between their resistance values cause unbalance. Their dissimilar magnetic environments lead to a difference in oxygen concentration around them and this causes an unbalance in the bridge indicative of the amount of oxygen in the gas mixture. The bridge output can be displayed on indicators or recorders and can also be used to operate ancillary controls or alarms. Sensitivities corresponding to a full scale deflection of down to 1% of oxygen can be provided for most gas mixtures.

Differential cathode-ray polarograph. Nash and Thompson, Hook Rise, Tolworth, Surrey.

This polarograph developed by Davis and Seaborn at the United Kingdom Atomic Energy Authority possesses very high sensitivity and offers facilities for subtractive, comparative and derivative methods of differential polarography (using two cells) and also for single cell work. When used with a single cell it provides all the facilities of the

single sweep cathode-ray polarograph, but in addition provision is made for base line slope correction and cancellation of current due to reductions at or below sweep start potential. A short time constant network may be employed to obtain derivative displays of all the current waveforms produced by both differential and single cell methods.

NaI(Tl) crystal-photomultiplier assemblies. Nuclear Enterprises (G.B.) Ltd., Bankhead Medway, Sighthill, Edinburgh, 11.

NaI(Tl) crystals of high purity and uniform thallium concentration are used with specially selected photomultipliers. The assemblies are completely light-tight, and are all fitted with magnetic shields around the photomultiplier. Cathode follower preamplifiers incorporating the dynode resistor chain can be fitted to all assemblies.

The assemblies fall into two main classes: integral and demountable. In the integral assembly the crystal is mounted directly on to the photomultiplier face, the complete assembly being hermetically sealed. All crystals up to and including 2 in. diameter are mounted in this way with the exception of one thin crystal unit which is mounted independently.

In the demountable assembly, the crystal is mounted independently and viewed through an optical window. In this assembly the photomultiplier can be easily replaced, not requiring the whole assembly to be returned to the firm for replacement as with the integral type. All the larger crystals (2 in. and upwards) are mounted in this way.

Where very low level activities are to be measured, it is essential that the background activity from the detector head itself be kept as low as possible. The NaI(Tl) crystals employed have a potassium content of 1 to 3 parts per 10^6 , and activity arises mainly from the glass window, the crystal canister and the photomultiplier tube base. The special low activity assemblies used employ quartz windows, stainless steel canisters and de-based photomultipliers.

For applications where rays other than gamma rays are to be measured, special integral assemblies are available with thin CsI(Tl) crystals (for α particles and proton detection) and anthracene crystals (for β particle detection); and also with special large crystals (9 in. diameter) and with three or four photomultipliers.

It is stated that for the ^{137}Cs 0.661 mev gamma ray photo-peak the resolution for crystals up to 3 in. $\times$ 3 in. is from 7 to 9.5% and for larger crystals 8–10% and about 2% higher for well-type crystals. The resolution depends, of course, on the geometry of the particular crystal.

Notes and Comments

Lay-out of journal

Readers will notice that the lay-out of the journal has been slightly altered in that each paper now begins on a fresh page. The Committee has decided to start this new system at once in order to increase the speed of publication of papers and reproduction of reprints and also to improve the look of the journal. As a result of this change some items from the Notes and News section may be published at different parts of the journal instead of all together at the end as they have been in the past.

Corrigendum

Improved manufacturing technique for blood-flow probe by S. J. STERRETT, *J. Sci. Instrum.*, **38**, 59.

The reference MOWBRAY, J. F., 1959, *J. Appl. Phys.*, **30**, 647, should read MOWBRAY, J. F., 1959, *J. Appl. Phys.*, **30**, 647.

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Micro-tensile testing machine

by D. M. MARSH, M.A., Tube Investments Research Laboratories, Hinxton Hall, Cambridge

MS. received 6th January 1961, in revised form 2nd March 1961

Abstract

This paper describes a tensile testing machine for microscopic specimens. It can apply loads in the range from 1 mgf to 400 gf to specimens having cross-sectional areas down to 10^{-7} mm². Specimen extensions from a few angstrom units to 15 mm can be measured and, at constant temperature, random errors in the extension measurement system are less than 5 Å (5×10^{-7} mm). The machine employs a torsion balance to apply the loads and a mirror-autocollimating telescope system to detect the extensions. Since it depends wholly on mechanical and optical principles it is practically drift-free at constant temperature. It is adaptable for tests in special atmospheres, for autographic recording and for tensile testing of thin films.

1. Introduction

THE tensile testing machine described in this paper was developed to investigate the mechanical properties of 'whiskers' and other small crystals, but is suitable for any similar specimens.* In its present form it can test specimens having cross sections from 10^{-7} mm² to 10^{-2} mm² and having lengths from 0.5 mm to 15 mm. It can apply loads from 1 mgf to 400 gf and can measure extensions up to 15 mm, the lower limit being set by random errors of about 5 Å. These quantities were chosen for the author's purposes, and in no way represent absolute limits of performance.

In designing micro-tensile testing machines the loads involved present little problem, as they are well within the range of normal balance practice. However, the necessary extension sensitivity is considerably more difficult to achieve. A number of such machines using electrical or electronic extension detectors have already been described, but their sensitivities have not been greater than about 1000 Å. When considering measurements of the order of a few angstroms, the problem of sensitivity is overshadowed by stability requirements, and in the present instance it was considered that the normal electronic systems are insufficiently drift-free. Thus the machine is wholly mechanical and optical in construction, with special provisions to ensure stability.

The present design replaces a previous machine which was described in an earlier paper (Marsh 1959, to be referred to as I). The new machine is much more accurate, is self-contained and less susceptible to draughts and is simpler to use.

2. Design principles

Figure 1 is a diagram illustrating the basic principles of the machine. A load is applied to a specimen by a torsion

balance 1, 2, 3. The torsion head arm 1 transmits torque to the torsion wire 2, thus applying a tensile load to the specimen. The extension of the specimen upsets the null

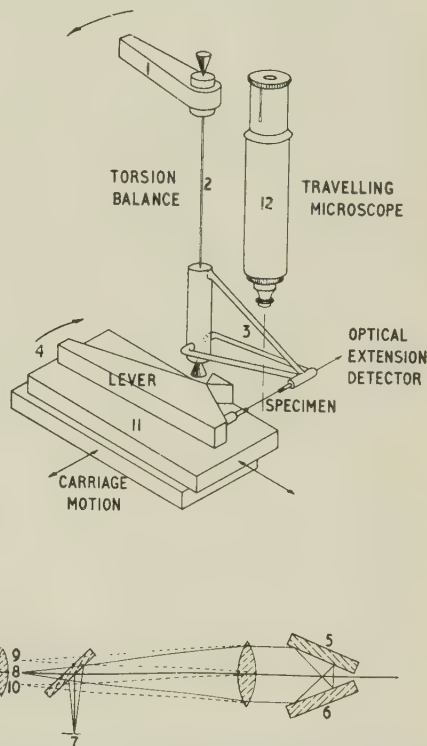


Fig. 1. Basic principles of the micro-tensile testing machine.

condition of the optical extension detector. This null condition is restored after each load increment by withdrawing the specimen, using the lever and a micrometer at 4.

Thus the method is essentially a null method, which allows a very sensitive extension detector to be used while still permitting very large extensions to be measured. It also ensures that the load is strictly proportional to the torsion head rotation, since the beam position 3 is the same at each reading. Further, the small loads imposed by the optical system are constant at the reading position and no linearity demands are placed on the motion of the optical system. Another advantage of the null method is the ease with which specimens might be enclosed for tests in special gases at atmospheric pressure.

The torsion balance was chosen for the load application because of its simplicity, stability and large range coverage with a series of interchangeable torsion wires. Other reasons for choosing a null method and a torsion balance have been discussed more fully in I, together with a review of other possible measuring techniques.

* An agreement has been made with Techne Ltd. of Duxford, Cambs., whereby they have sole manufacturing and sales rights on this instrument.

The main advantages of an optical extension detector lie in its relative simplicity and inherent freedom from drift, which limits the sensitivity of machines of this kind. Interferometric systems are insufficiently sensitive in their simple forms, since to attain sensitivity of $2.5 \text{ \AA}$ would require the detection of 0.001 fringe shift. Attention was therefore concentrated on various mirror systems.

The basis of the mirror system used is shown in the inset to Fig. 1. Two mirrors 5 and 6 receive light from an auto-collimating telescope. When the mirrors are at 45° to one another, they reflect the light as shown by the full lines and return it to the telescope to form an image of the graticule 7 at 8. However, if the angle departs from 45° then the light paths are as shown by the dotted lines and two images 9 and 10 are formed. Thus the 45° condition is indicated by the merging of the two images 9 and 10 to form one central image 8, and this gives an excellent null condition with the following advantages:

(i) the sensitivity is much higher than that of a simple optical system because of the multiple reflections involved. This reduces the need for mechanical amplification and hence reduces the forces which the system imposes on the specimen;

(ii) the null condition is only upset by two of the eighteen degrees of freedom of the system considered (Twyman 1952). One is the rotation of 5 as a result of the specimen extension and the second is a similar rotation of 6, which is therefore used as a zeroing device. Since the other degrees of freedom of the mirrors and telescope do not matter, no care is needed to prevent these movements.

In addition to the main components described above there are the following extra items. To enable specimens to be aligned and to allow of various lengths of specimen, the plate 11 carrying the lever system is mounted on a two-dimensional carriage mechanism. To check this alignment and to measure the specimen length a travelling microscope 12 is installed over the specimen centre line. There are also heating arrangements for melting the glue on the grips and a lamphouse to illuminate the specimen during mounting.

A general view of the machine appears in Fig. 2 and a plan view of the mechanism with the lids and travelling microscope removed is shown in Fig. 4. The basic structure is a heavy box into which the various sub-assemblies, labelled in

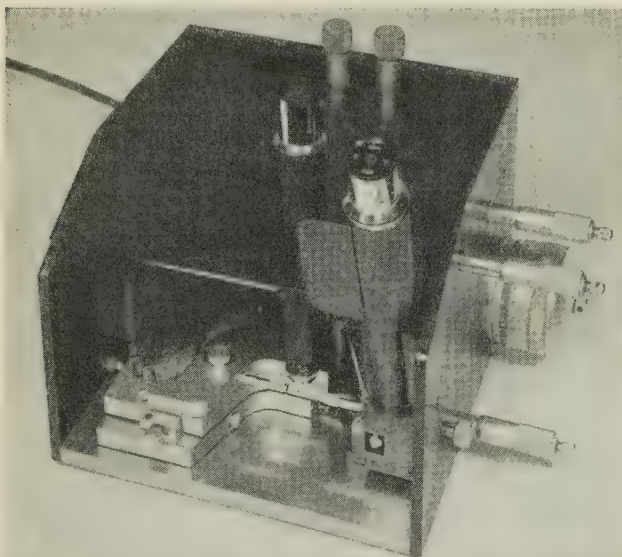


Fig. 2. General view of the micro-tensile testing machine.

Fig. 1, are fitted separately. Great care was taken in placing the components to ensure operating convenience and this has been amply repaid in increased ease of operation and accuracy, with less strain on the operator.

The accuracy of the machine depends at least as much on the detailed design of components as on the general principles discussed above. In particular it depends on being able to construct a variety of simple flexure pivots. These are described in another paper (Marsh, to be published, to be referred to as III), and only the briefest description will be given here. The rotating element is always secured to the standing component by one or more strips or wires which provide a pivoting action by bending. There is no backlash or friction (other than internal friction) in such pivots by proper design is essential.

The stress scale for each specimen is obtained from the measured elastic strains and the known value of Young's modulus, as it was in the previous machine. The usual method involving measurement of the cross-sectional area is very inaccurate with microscopic specimens. Another difference from microscopic testing is that the whole distance between the grips is the gauge length. The accuracy of the assumed gauge length has been verified by mounting different lengths of the same whisker, when the measured strains for a given stress were found to be independent of the mounting length and thus were not subject to end effects.

3. The torsion balance

An isometric view of the torsion balance is shown in Fig. 3. The main framework consists of a flat base 1

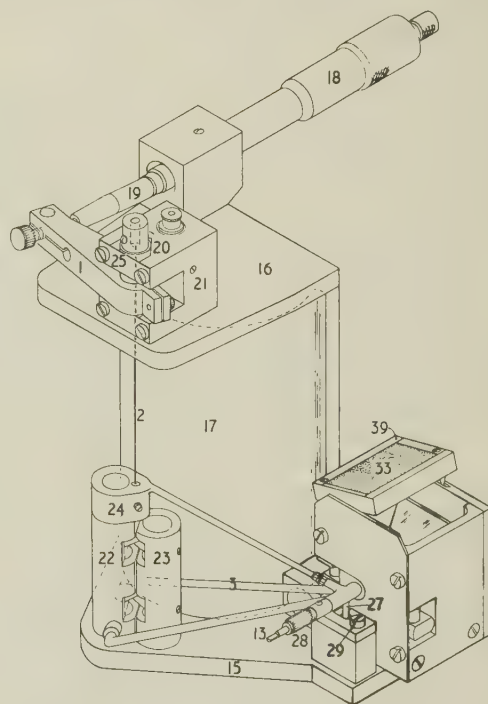


Fig. 3. Isometric view of the torsion balance.

and top plate 16 attached by a semi-tubular column 17. The micrometer 18, acting through the push rod 19 and arm 16, rotates a tube 20, pivoted in vee blocks 21; and hence rotates the top end of a torsion wire 2. The freely swinging beam is hinged by a cross-spring pivot 22, 23, and the torsion wire is attached to this beam at the boss 24. Thus rotation

f the head mechanism by the micrometer 18 applies a tensile load to a specimen attached at 13. A ball-ended screw in the arm 1 allows coarse force zeroing to be carried out—the fine zeroing being provided in the extension detector system.

The torsion head must be accurately reproducible in its action and this is ensured by the kinematic tangent screw mechanism. Now a simple tangent screw suffers from a substantial sine error (see I). However, the push rod 19 perturbs this error because of its varying obliquity during the rotation, and by suitable choice of dimensions this obliquity can compensate largely for the sine error. In this way the 0.7% error of the simple system over 25° is reduced by a factor of ten.

The five interchangeable torsion wires are made of beryllium copper in the worked and hardened state and are hardened into end rods. Since the end rods have a larger diameter than the wires, the errors introduced by removing and replacing the wires are negligible. The torsion wires are secured to the tube 20 at its top end by a set screw so that much of the length of the tube 20 is available as free torsion wire length thus reducing the height of the whole balance for a given torsion wire length. Torsion wires can be dropped in at the top of tube 20 thus facilitating wire hanging.

The two groups of hinges at 22, 23 are widely separated vertically to give stability and are equally spaced above and below the specimen level, so that movement due to yielding of the pivot about a horizontal axis tends to cancel out at the specimen. The rotating half of the hinge 22 is placed behind the axis of rotation to help counterbalance the beam, and the stiffness of the pivot is chosen to be comparable with the stiffness of the mirror system with which it is in parallel.

The other end of the beam carries a peg 27 and a collet chuck 28 which in turn holds the specimen grip 13. The free motion of the peg is limited by a slot, adjustable by screw 29. This arrangement protects the mirror system against violent movements and can be adjusted to make the machine 'hard'. The lower end of the peg dips into a dash pot which, together with a similar dash pot in the mirror system, provides critical damping for the torsion balance-extension detector system.

The preferred specimen grips for fibres, 13 and 14 in the inset to Fig. 4, consist of fused silica rods ground to give flat spades. Specimens can be glued to these grips using molten sym-diphenyl carbazide heated by a type of small soldering iron. The contraction of the grips and consequent loading of the specimen is minimized by the use of fused silica. Provision is also made for integrally heated grips, the arrangement being similar to that described in I. The grips for film testing consist of inverted spades 30, 31, shown in the inset to Fig. 4. Films can be conveniently presented by floating them on a meniscus contained by a square aperture 32. They are centred in the hole by the repulsion due to surface tension acting between the unwetted film and the wetted sides of the hole. They are also held taut by the surface tension and are automatically oriented by using a square piece of film in the square aperture. They are raised slowly by ejecting the meniscus upwards with a plunger. This gives a curved surface which touches the front edge of the grips first and then is wrapped smoothly over the glued surface. The positioning is thus wholly automatic but precludes the use of diphenyl carbazide glue. At the present time there is a lack of alternative glues, although Araldite (by CIBA (A.R.L.) Ltd.) might be suitable.

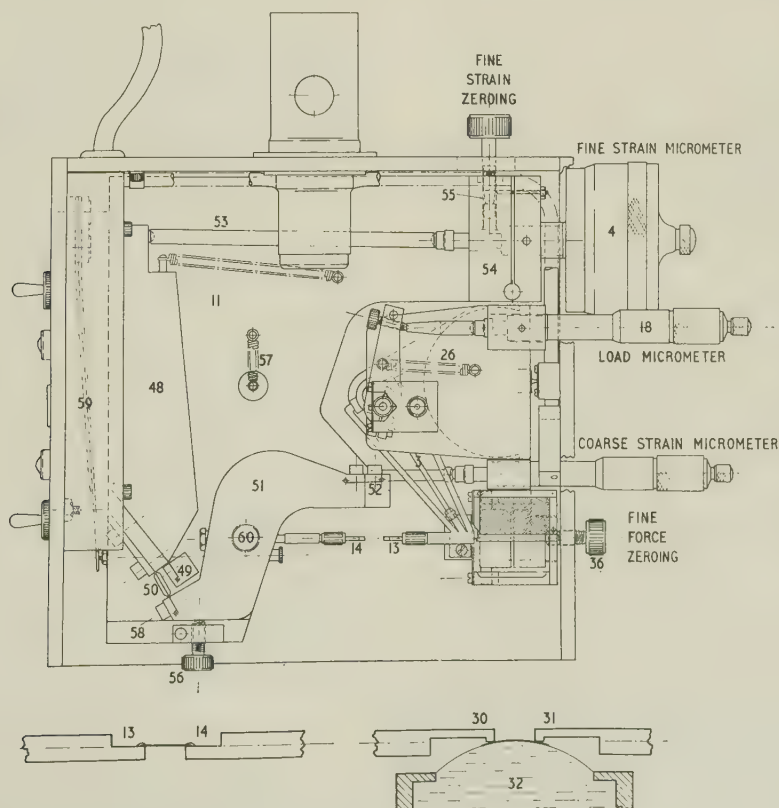


Fig. 4. Plan view of the machine with lids and travelling microscope removed.

Inset left. Arrangement for gripping 'whiskers'.

Inset right. Arrangement for mounting films.

4. The extension detector

The mirror system

In § 2 the basic principle of the extension detector was established. In designing the mirror system it was considered essential that the rotating mirror be mounted on a flexure pivot to eliminate friction and backlash. This flexure pivot is in parallel with the specimen stiffness and so must be very compliant if the sensitivity is not to be reduced.

In practice, the system of two mirrors at 45° with an autocollimating telescope is slightly modified, as shown in Fig. 5.

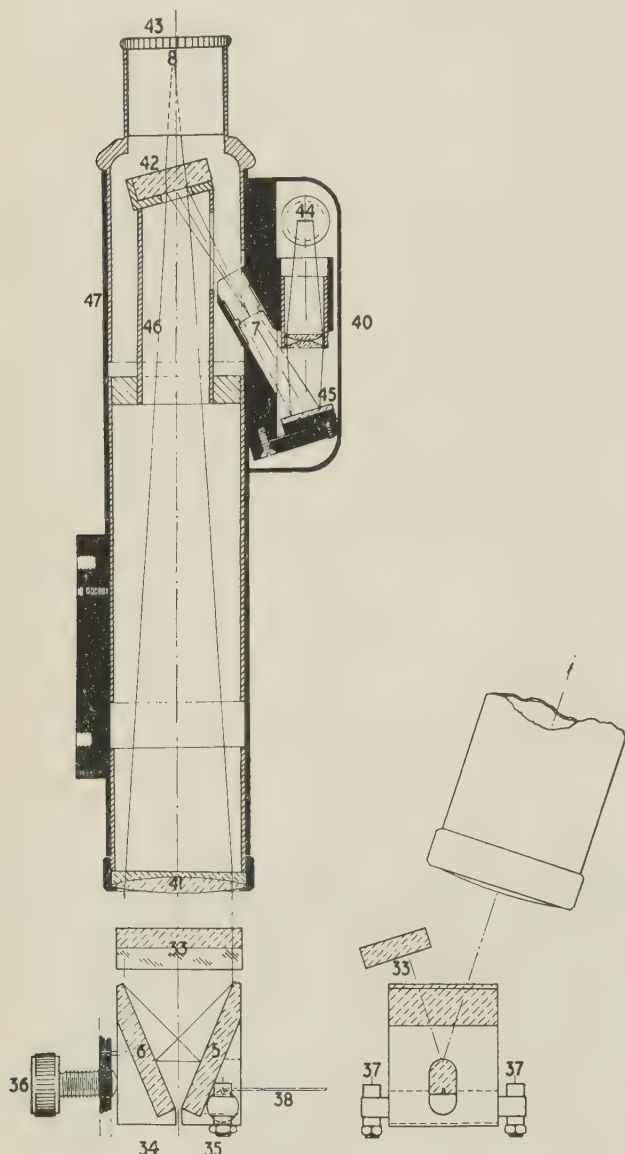


Fig. 5. Sectional view of autocollimating telescope and mirrors.

Light from the telescope is reflected at the two mirrors 5 and 6 as described, but instead of returning to the telescope after the fourth reflection it is reflected by the mirror 33 so that it retraces its previous path back into the telescope along its incident route. This arrangement results in a system of two images which coincide at the 45° position as before but has the following two advantages:

- (i) the telescope axis no longer has to be in the plane normal to mirrors 5 and 6. Thus the telescope can be placed at an angle convenient to the user and the mirrors can be placed where convenient for their suspension and linkage;
- (ii) the sensitivity is doubled.

This system readily gives an absolute sensitivity of $1 \text{ \AA}$. The main mirror block is shown in Fig. 3 and some further details are shown in Fig. 5. Two mirrors flat to 0.1 fringe are mounted on triangular mounts 34 and 35. Mount 34 is pivoted on wire pivots and can be rotated by the screw 36. This adjustment is used to zero the images before a test and in normal use is the fine force zeroing control (see Fig. 3). The other mount is hinged by two short lengths (of the order of 0.005 in.) of 0.001 in. strip, which are held by simple clamps at 37 in the mount and main mirror block. A fibre 38 attaches the torsion balance to the mirror. This is deliberately arranged to have an appreciable length to isolate the mirror from side movements of the torsion beam, as a cross-spring pivot may deflect under load by distances large compared with the extension sensitivity and would otherwise produce serious second-order errors at the mirror. The thin fibre is stiffened by hypodermic tubing as shown to give the system a higher buckling strength for a given flexure rigidity, and is contained in the end tube (Fig. 3) of the torsion balance to protect it from temperature fluctuations and damage.

Mirror 33 (Fig. 3), which causes duplication of the system, is mounted on top of the block on a single wire pivot 39 and is adjustable in two directions by two screws, one of which is located in a groove to prevent rotation about the axis of the wire 39.

The telescope

The telescope (Fig. 5) carries a lamp house 40 which illuminates the graticule 7 at the focus of the lens 41. The lamp house is outside the main box to eliminate temperature fluctuations. Light from the graticule is reflected down the telescope tube by the half-silvered mirror 42 and on returning to the telescope forms an image at 8 which is viewed by the $\times 50$ eyepiece 43.

The small 2 w bulb 44 is centred by a movable bracket to throw light through a double condenser to the graticule by the mirror 45. The graticule holder 7 slides in its mounting tube, and tube 46 carrying the half-silvered mirror 42 is able to rotate and slide up and down the main telescope tube 47. In this way the three perpendicular centring and focusing motions required by the graticule are provided very simply. The objective 41 is a simple achromatic doublet with its curved face downwards. This eliminates an awkward reflection from one of the lens faces.

A bright line graticule is used at 7 so that the two images 9 and 10 (Fig. 1) may be regarded as Young's double slits which can produce mutual interference. In particular at the coincidence position they have a characteristic 'focus' appearance which gives a positive indication of coincidence thus increasing accuracy and reducing eye-strain. To see the diffraction effects clearly, a $\times 50$ eyepiece is used and the resulting setting accuracy is about four times that expected from the normal Rayleigh criterion.

5. The lever mechanism

The reduction ratio of $100 : 1$ between the drum micrometer 4 and the specimen grip 14 (Fig. 4) is achieved in two stages. Withdrawal of the micrometer 4 rotates the lever about its single strip flexure pivot 49 and provides a twenty-

five-fold reduction of motion at the connecting strap 50. This is further reduced by the lever 51 pivoted at 52 to give a hundred-fold reduction at the grip 14. Despite the risk of additional errors it was considered essential to divide this reduction into two stages for the following reasons:

(i) the lever arm between 14 and 52 could then be kept long compared with the possible error in the position of the whisker on grip 14, thus reducing the changes of ratio which such mounting could give;

(ii) the instantaneous centres of the flexure pivots move a known amount for a given rotation and the shortest lever arm between 49 and 50 must be long enough for this shift to be unimportant. This necessitated a double reduction of motion if reasonable overall dimensions were to be maintained. The smooth action of the levers is provided by steel balls pressed into the underside of the levers and sliding over the ground, chromium-plated surface of plate 11. The pivoting strips at 49 and 52 have a free length of about 0.001 in. and a thickness of about 0.003 in. so that they provide rotation without assuming an S-shape. However, care was taken to place these grips such that any residual motion was in an unimportant direction. Further, the grip 14, pivots 52 and 49, connecting strap 50 and micrometer axis 4 are arranged to be co-planar to reduce second-order errors due to random vertical movements of any of these components.

The drum micrometer 4 is mounted on the free arm of a horseshoe 54 of high-tensile steel, which can be sprung open by a cone 55 on a screw. This adjustment screw is the fine strain zeroing screw. To facilitate the finest measurements an additional 10 : 1 lever may be fitted between the push rod 53 and drum micrometer 4 to give a 1000 : 1 reduction ratio. A vernier of the micrometer then reads to 10^{-4} mm, which represents a specimen extension of 1 Å.

The whole of the lever mechanism is carried on the two-dimensional ball carriage mechanism 11, 58, driven by screw 56 and the coarse strain micrometer against springs 57, 59, while vertical motion of grip 14 is provided by knob 60. These motions provide for specimen alignment and for coarse strain measurement when the drum micrometer motion is exhausted.

6. The travelling microscope

The travelling microscope (Fig. 6) moves on the balls 61 rolling on a vee-bar 62 and a rod 63. It is held to the operating

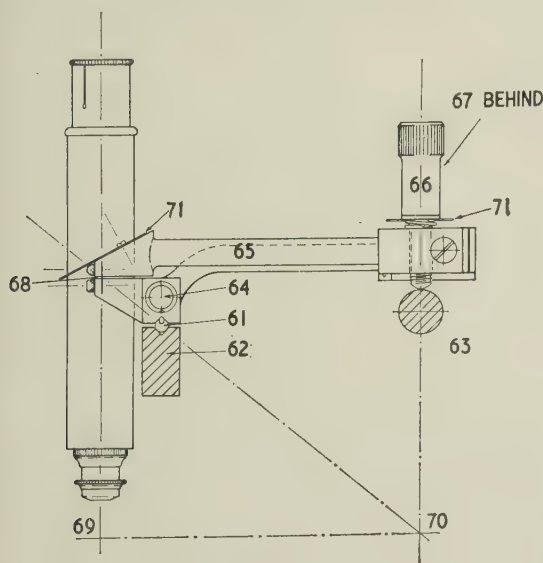


Fig. 6. Elevation of the travelling microscope.

micrometer by the 'pot' magnet 64, which also provides the hard surface for the micrometer ball end. Beside providing a constant load, the magnet has the advantage that it only operates when in contact with the micrometer. Thus for mounting specimens, the microscope is pushed away by hand from the vicinity of the grips and remains out of the way until pushed back, when it automatically rejoins the micrometer.

The transverse and focusing motions are provided very simply by the extra arm 65 and two screws 66 and 67. Rotation of screw 66 rotates the microscope about the simple flexure pivot 68 and moves the image point 69 in a horizontal arc through the small distance required without loss of focus. Similarly, rotation of screw 67 gives a vertical motion to the image point 69. Although this motion is also an arc it is instantaneously vertical at 69 if the vertical through 66, the horizontal through 69 and the line through 68 and 61 meet at a single point 70. Under these conditions there is no apparent transverse motion of the image through the whole focusing range. Finally, shutters 71 close the slots in the lid to minimize draughts in the machine.

7. Calibration and errors

The torsion balance was calibrated by mounting it on its side and using a scale pan and weights. The lever system was calibrated by two methods. In the first the lever arms were accurately measured on a universal measuring machine reading to 10^{-5} in. For the second method the overall lever ratio was determined by joining the grips and balancing large drum micrometer movements with the coarse strain micrometer, using the extension detector as a null indicator.

Careful measurements of the non-linearity of the load scale showed that it agreed closely with the calculated errors of 0.07% full scale. Any random or other systematic errors were certainly no larger than this figure. An upper limit to the random errors of the lever and mirror systems combined is provided by some measurements of the repeatability of extension scale readings. With the grips joined together to eliminate specimen effects, and taking certain precautions to minimize temperature fluctuations, the repeatability was found to be 4.3 Å (standard deviation of 40 readings). Systematic errors of the lever system are harder to find as no test equipment available has a sensitivity approaching the necessary value. However, this type of drum micrometer has proved linear to 0.001% full scale over the limited distance for which highly sensitive measurements are required, and should be accurate to 0.01% over its whole range. The only potential source of trouble in the levers themselves is their frictional contact with the carriage, but any resulting stick/slip or hysteresis has proved too small to detect. One error due to the mirror system arises if the null position is not found exactly before each successive reading. The stiffness of the mirror then exerts a small load on the specimen. This 'force interference' is only about 0.15 mgf for a 50 Å setting error and so is not serious.

8. Mode of use

The machine is easier to use than the earlier model. With the load and strain micrometers at zero, the torsion wire is changed if necessary and the extension detector images are zeroed by the coarse and fine force zeroing controls. The specimen is then glued in position and is aligned to the travelling microscope axis by the specimen alignment knobs. Care is taken to melt the glue to eliminate any specimen bends caused by the alignment procedure, lamp 71 is switched

off and the system is allowed to come to thermal equilibrium. The extension detector images are then re-zeroed by the coarse and fine strain zeroing controls to remove any loads imposed during the mounting. Testing is carried out by alternately loading by the load micrometer and zeroing by the fine strain micrometer, and a complete set of ten points can be read and recorded in 90 seconds. In some tests the extension may exceed the 0.25 mm range of the fine strain micrometer and further extensions are followed on the coarse strain micrometer.

9. Possible developments

The present machine is manually operated but might be extended to give automatic strain recording over a limited range, at the expense of some complication. This would involve an adaption of an extremely sensitive device due to Jones and Richards (1959). A photogrid of a suitable design would replace the graticule 7 and a similar photogrid and double photocell would replace the eyepiece. The effect would be as described by Jones and Richards, but with the addition of the valuable independency properties discussed above.

Another possible development is an adaption to permit testing in controlled atmospheres. A cylindrical container could be clamped to the base plate such that the specimen grips lie along its axis. The ends of the container would consist of flexible bellows sealed to the grips to give an air-tight system. The constraint imposed upon the torsion balance by the bellows would be immaterial since a null method is used, but it would be desirable for the bellows to be less stiff than the specimen if the full extension sensitivity is required.

10. Summary

A tensile testing machine capable of testing a wide range of small specimens has been described, together with performance figures which themselves can be varied over wide limits. It is capable of modification to include automatic recording of extensions and the testing of specimens in special atmospheres. Its chief characteristic is a very high extension sensitivity, together with an ability to test very small crystals ($\sim 10^{-7}$ mm² cross section). It was developed mainly for tensile testing of single crystal 'whiskers', but may well have more general applications in testing fibres and thin films.

Acknowledgments

The author wishes to thank Mr. J. E. Gordon, Dr. J. V. Menter and other colleagues for their encouragement and helpful criticism of the manuscript. He also wishes to thank Mr. H. A. Nightingale and Mr. F. Buckingham who constructed the machine, and Mr. A. E. Long of the Cavendish Laboratory who spent a considerable time setting up and testing the various components of the machine. He is grateful to Mr. M. D. W. Paddison for his care in preparation of the diagrams.

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Basis of verification of metal and glass Sikes hydrometers

by P. H. BIGG, B.Sc., F.Inst.P., National Physical Laboratory, Teddington, Middlesex

MS. received 2nd January 1961

Abstract

The basis of verification of metal Sikes hydrometers has been refined as the outcome of discussions between the Laboratory of the Government Chemist and the National Physical Laboratory. The refinement takes the form of the adoption of conventional reference conditions for the wetness of the hydrometer stem above the liquid surface and the surface tension pull acting on it. Corresponding refinement in the reference conditions associated with the glass hydrometers has been adopted by the N.P.L. These refinements will lead to greater consistency in verification and will not affect the ordinary calibration of Sikes hydrometers, except for glass hydrometers used in very dilute solutions. Full details for the precise verification of both metal and glass Sikes hydrometers are given.

1. Introduction

THE metal Sikes hydrometer has long been used in this country. It dates from 1802 when the Treasury sought improved methods for assaying spirits, and a scientific committee chose for the purpose the hydrometer and tables submitted by Bartholomew Sikes, a former Secretary of Excise.

The hydrometer consists of a gilded brass bulb 1.5 inches in diameter which supports a thin rectangular stem uniformly engraved in 10 degrees, each with five subdivisions; it is weighted by a short tapering rod ending with a counterpoise. At 60° F the indications correspond to 66.7 over proof* at the top (0 Sikes), and 58.4 over proof at the bottom (10 Sikes). For lower spirit strengths than this the instrument is too light and it is weighted by means of gilded brass 'poises' which rest singly on the counterpoise and are immersed in the liquid tested. Nine such poises are used, numbered 10, 20, 30...90. Their volumes and masses are such that they furnish a continuous range of indication from 0 to 100 Sikes, the latter corresponding to pure water. The hydrometer is normally used in conjunction with tables relating the readings to percentages of proof spirit. The ordinary Sikes hydrometer has been supplemented by less dense instruments suitable for stronger spirits. In this country this was done in two stages; first, instruments of range A0 to A10 were introduced, where A10 corresponds to 10 Sikes and later, as stronger spirits became available, the range B0 to B10 was adopted where B10 = A0. In India the scale was extended in one step to cover the same total

range and the extension was designated A0 to A20, A0 being equivalent to B0 on the (later) English scale and A20 being the same as 0 Sikes.

Until relatively recently the practical maintenance of the Sikes scale has depended on reference instruments in the custody of the Laboratory of the Government Chemist (L.G.C.) and its predecessors. This was no easy task because the gilt surface was very liable to wear and, gold being dense, this led to appreciable changes in calibration. Nevertheless, the Customs and Excise authorities were committed to using the metal Sikes instrument and it was retained, even when glass hydrometers came into common use. Improved ways had to be found of maintaining the metal standard. The tables associated with the hydrometer comprised not only Sikes-proof strength data, but also a Sikes-weight per gallon table, and from the latter, and by other means, it was possible to calculate the density or specific gravity equivalents of the Sikes scale, though not so accurately as one might have wished for the purposes of verification of Sikes hydrometers. But because the prescription for using the hydrometer was not sufficiently closely described for verification purposes, the equivalents could not be applied with precision, and this remained the case when more precise equivalents later became available.

However, the basis of verification of metal Sikes hydrometers has recently been refined as the outcome of discussions between the L.G.C., which is still basically responsible for the Sikes scale and verifies metal Sikes hydrometers for the Customs and Excise authorities, and the National Physical Laboratory (N.P.L.), which is responsible for certain other tests on Sikes hydrometers. The refinements take the form of conventional reference conditions for the wetness of the stem of the hydrometer above the liquid surface and the surface tension pull acting on it when the hydrometer is in use.

Although in the British official usage of Sikes hydrometers only metal instruments are used, in India the official instruments are of glass. Glass instruments are also used, for various non-official purposes, in this country. It was desirable, therefore, to lay down reference instrumental conditions for glass Sikes hydrometers and, as glass instruments behave rather differently from metal instruments, these reference conditions had to be special to them. Nevertheless, in considering glass hydrometers the corresponding use of the metal instruments had to be taken into account. Now that reference conditions for metal instruments have been adopted, the N.P.L. has adopted correspondingly refined reference conditions for glass instruments.

This paper places on record the reference instrumental refinements now associated with verification. It also states the officially accepted specific gravity equivalents of the Sikes scale. Further, for convenience in the precise verification of metal and glass Sikes hydrometers, the paper gives the specific

* Proof spirit was defined (56 Geo. III. c. 140) as spirit of strength such that at 51° F it 'weighs exactly twelve thirteenths parts of an equal measure of distilled water'. Its specific gravity 60/60° F (in air) is 0.919 76 and it contains 49.28% of alcohol by weight or 57.10% by volume at 60° F. On dilution, one hundred volumes of spirit of strength P over proof will produce $P + 100$ volumes of proof spirit, and 100 volumes of spirit at P under proof contain $100 - P$ volumes of proof spirit.

gravities 60/60° F that correspond to the use of both types of hydrometer with the stem dry.

2. Metal Sikes hydrometers

(a) The specific gravities given in Table 1 are regarded as the 'legal densities of flotation'; that is, the Sikes scale, in abstract, corresponds to the specific gravities which are there quoted.

(b) The adopted relationship between the specific gravity 60/60° F in air (i.e. the ratio of the weights in air of equal volumes) and true specific gravity 60/60° F (i.e. the ratio of the masses of equal volumes) is as follows:

Sp. gr. 60/60° F in air =

$$\text{Sp. gr. 60/60° F} - 0.0012 (1 - \text{Sp. gr. 60/60° F}). \quad (1)$$

(c) In the method prescribed by the Commissioners of Customs and Excise for using metal Sikes hydrometers, the

instrument is depressed to division 0 and is then slowly allowed to rise to its resting point before taking a reading. Consequently, when the hydrometer is read in service, the stem is wet, but because the amount of liquid adhering to the stem depends on the surface conditions (particularly when the solutions are dilute), as well as on the lapse of time before reading the instrument, the effect on the reading differs appreciably from occasion to occasion. Therefore, for consistency in standardization it has been decided to verify the hydrometers with the stem dry above the meniscus and to make conventional allowances for the effect of wetting the stem in service.

The allowances (which are based on experimental determinations at the L.G.C. and the N.P.L.) are given in Table 1. They vary from point to point along the stem, but at any one point on the stem they are the same, irrespective of the sinking poise or the hydrometer used.

(d) Because of the wide variations of both the effect

Table 1. *Specific gravity equivalents of the Sikes scale*

Indication	Sp. gr. 60/60° F in air	Indication	Sp. gr. 60/60° F in air	Indication	Sp. gr. 60/60° F in air
B 0	0.782 69	21	0.851 28	64	0.929 32
B 1	0.784 28	22	0.853 02	65	0.931 22
B 2	0.785 89	23	0.854 77	66	0.933 12
B 3	0.787 50	24	0.856 52	67	0.935 03
B 4	0.789 12	25	0.858 29	68	0.936 95
B 5	0.790 74	26	0.860 05	69	0.938 87
B 6	0.792 37	27	0.861 83	70	0.940 85
B 7	0.794 01	28	0.863 61	71	0.942 79
B 8	0.795 66	29	0.865 41	72	0.944 70
B 9	0.797 30	30	0.867 16	73	0.946 61
B 10 }	0.798 97	31	0.868 88	74	0.948 53
A 0 }		32	0.870 65	75	0.950 47
A 1	0.800 60	33	0.872 43	76	0.952 40
A 2	0.802 23	34	0.874 22	77	0.954 34
A 3	0.803 88	35	0.876 01	78	0.956 30
A 4	0.805 52	36	0.877 81	79	0.958 26
A 5	0.807 18	37	0.879 62	80	0.960 23
A 6	0.808 84	38	0.881 44	81	0.962 18
A 7	0.810 51	39	0.883 26	82	0.964 12
A 8	0.812 19	40	0.885 03	83	0.966 07
A 9	0.813 87	41	0.886 78	84	0.968 02
A 10 }	0.815 55	42	0.888 58	85	0.969 98
0 }		43	0.890 39	86	0.971 96
1	0.817 22	44	0.892 21	87	0.973 93
2	0.818 90	45	0.894 04	88	0.975 92
3	0.820 58	46	0.895 88	89	0.977 92
4	0.822 28	47	0.897 72	90	0.979 92
5	0.823 97	48	0.899 58	91	0.981 90
6	0.825 68	49	0.901 43	92	0.983 87
7	0.827 39	50	0.903 26	93	0.985 86
8	0.829 11	51	0.905 06	94	0.987 85
9	0.830 84	52	0.906 90	95	0.989 85
10	0.832 47	53	0.908 74	96	0.991 85
11	0.834 07	54	0.910 60	97	0.993 87
12	0.835 79	55	0.912 46	98	0.995 89
13	0.837 50	56	0.914 33	99	0.997 92
14	0.839 22	57	0.916 20	100	1.000 00
15	0.840 95	58	0.918 08		
16	0.842 69	59	0.919 98		
17	0.844 43	60	0.921 85		
18	0.846 19	61	0.923 69		
19	0.847 94	62	0.925 56		
20	0.849 63	63	0.927 44		

the surface tension T of a dilute alcohol solution of given strength and the contact angle θ between the solution and the hydrometer stem, it has been found desirable for consistency to relate the verification of metal Sikes hydrometers to conventional average values of the product $T \cos \theta$. Over most of the range of the hydrometers, this product can be regarded as identical with the surface tension T of clean surfaces of solutions of the strengths concerned, but for two reasons this becomes untrue as 100 Sikes is approached: (i) in dilute solutions the meniscus does not wet the hydrometer stem, i.e. the angle of contact is greater than zero and $\cos \theta$ is less than unity; (ii) the effective surface tension force on the more dilute solutions is reduced also by the fact that the actual surface tension in service is generally less than that of perfectly clean surfaces. The adopted conventional values of $T \cos \theta$ are given in Table 3. They are based on experimental evidence obtained at the L.G.C. and at the N.P.L.

(e) Table 4 is based on the conventions set out above. It gives the true specific gravities corresponding to the dry-stem readings of metal Sikes hydrometers, subject to the adopted conventional surface tension forces, and is intended to be of help to manufacturers and, more particularly, as a precise basis of reference for the purpose of verification. The specific gravity values have been derived from those in Table 1, making appropriate allowances according to expression (1) and Table 2. The following example is given by way of illustration.

Suppose the hydrometer indication, taken at 60° F after sinking the instrument to zero and letting it rise in the prescribed manner, is 74.94.

By interpolation in Table 1 the specific gravity 60/60° F in air of the liquid should be 0.95035, and by means of expression (1) it is found that the true specific gravity 60/60° F would be 0.95041.

As the indication of the hydrometer with the stem wet is 74.94, the corresponding reading with the stem dry is according to the conventional figures set out in Table 2) $74.94 + 0.06 = 75.00$.

The surface tension pull $T \cos \theta$ per unit length of the cross-sectional periphery of the stem is (Table 3) taken to be 31.2 dyn/cm.

Consequently, at 60° F the metal Sikes hydrometer is accurate if it reads 75.00 with the stem dry, when the liquid has the specific gravity 60/60° F 0.95041 and the surface tension pull $T \cos \theta$ is 31.2 dyn/cm.

(f) It may be noted that though the adoption of the reference values for wetness of stem and of the conventional values of $T \cos \theta$ will affect refined calibrations of reference instruments on the basis of specific gravity, or the comparison

Table 3. Reference values of $T \cos \theta$ for metal Sikes hydrometers

Indication	$T \cos \theta$ (dyn/cm)	Indication	$T \cos \theta$ (dyn/cm)
B 0 at 85° F	21.8	40	27.2
B10 at 47° F	23.6	45	27.6
B10 at 60° F	23.1	50	28.0
A 0 at 60° F	23.1	55	28.5
A10 at 60° F	24.0	60	29.1
		65	29.8
0	24.0	70	30.5
5	24.4	75	31.2
10	24.8	80	31.9
15	25.2	85	32.6
20	25.6	90	33.4
25	26.0	95	34.2
30	26.4	100	35.0
35	26.8		

Table 4. True specific gravities, corresponding to readings on a metal Sikes hydrometer immersed at 60° F in liquid exerting the given surface tension pull, with the stem unwetted above the liquid surface

Indication (stem dry)	Poise	Sp. gr. 60/60° F (true, not 'in air')	Effective surface tension pull (dyn/cm) $T \cos \theta$
* †			
B 0 A 0	—	0.78295	21.8
B 5 A 5	—	0.79089	22.5
B10 A10	—	0.79901	23.1
A 0 A10	A	0.79921	23.1
A 5 A15	A	0.80731	23.6
A10 A20	A	0.81557	24.0
0	—	0.81577	24.0
5	—	0.82408	24.4
10	—	0.83247	24.8
10	10	0.83267	24.8
15	10	0.84104	25.2
20	10	0.84961	25.6
20	20	0.84981	25.6
25	20	0.85835	26.0
30	20	0.86711	26.4
30	30	0.86732	26.4
35	30	0.87605	26.8
40	30	0.88496	27.2
40	40	0.88517	27.2
45	40	0.89406	27.6
50	40	0.90316	28.0
50	50	0.90338	28.0
55	50	0.91246	28.5
60	50	0.92172	29.1
60	60	0.92194	29.1
65	60	0.93119	29.8
70	60	0.94068	30.5
70	70	0.94092	30.5
75	70	0.95041	31.2
80	70	0.96004	31.9
80	80	0.96028	31.9
85	80	0.96990	32.6
90	80	0.97970	33.4
90	90	0.97994	33.4
95	90	0.98974	34.2
100	90	0.99975	35.0

* British nomenclature.

† Indian nomenclature.

Table 2. Reading with stem wet minus reading with stem dry (main divisions)

Stem reading	Allowance
0	—0.00
1	—0.02
2	—0.02
3	—0.04
4	—0.04
5	—0.06
6	—0.08
7	—0.08
8	—0.10
9	—0.10
10	—0.12

of dissimilar instruments, ordinary tests on metal Sikes hydrometers by comparison with similar reference instruments will not, in principle, be affected.

3. Glass Sikes hydrometers

(a) By convention, glass Sikes hydrometers are calibrated on the basis of agreement at 51° F with standard metal Sikes hydrometers.

(b) It has been customary for nearly 50 years for the results of N.P.L. verification of glass Sikes hydrometers to apply to readings taken with the stem dry above the liquid meniscus. This practice will be continued.

(c) The value of $T \cos \theta$ quoted in Table 3 will be taken to apply equally to glass instruments up to and including the indication 70, but above this point higher values will be taken for glass than for the metal. (Up to indication 70, θ is effectively zero for both glass and metal, but above this it is so only for glass instruments.) The adopted values are those included in the third column of Table 5; those above 70 Sikes bridge satisfactorily between 30.5 dyn/cm at 70 Sikes and the value 55 dyn/cm conventionally adopted by the N.P.L. and the British Standards Institution hydrometer committee for water surfaces of ordinary laboratory cleanness. (Owing to liability to minute quantities of surface contamination, ordinary water surfaces do not usually exhibit the surface tension of pure water. Freshly poured tap water is often much better in this regard.)

(d) Finally, at 60° F, the glass instrument will indicate 0.07 Sikes less than the metal instrument, because the metal

and glass instruments agree at 51° F and have different thermal expansion.

(e) Table 5, which is based on the various considerations set out above, gives the true specific gravities corresponding to the dry-stem indications of glass Sikes hydrometers subject to the quoted surface tension forces. The following example is given by way of illustrating its derivation.

If a glass hydrometer, which (by definition) should agree with a metal Sikes hydrometer at 51° F, indicates 85 Sikes in a liquid at 60° F, the indications of the metal hydrometer under service conditions would be 85.07 Sikes.

From Table 1 the specific gravity 60/60° F in air of the liquid would be 0.97012, and from expression (1) it follows that the true specific gravity 60/60° F of the liquid would be 0.97016.

Consequently the glass hydrometer is accurate when at 60° F it indicates 85 Sikes in a liquid having a true specific gravity 60/60° F 0.97016 and the surface tension is 40 dyn/cm (third column of Table 5).

4. Conclusion

The above information is published for the benefit of those who manufacture or verify Sikes hydrometers, or are otherwise interested in the Sikes scale. The adoption of the new conventions will improve the realization of the Sikes scale at the standards laboratory, and for the most part it will cause no disturbance in ordinary work with Sikes hydrometers because the refinements have been designed with that in mind. But large changes will occur in readings of glass Sikes hydrometers in the neighbourhood of 100 Sikes, though these will have little practical significance because of the extreme dilution of the solutions concerned. At about 100 Sikes glass Sikes hydrometers will indicate 0.5 Sikes more than hitherto. The reason for this change is as follows. When the N.P.L. first undertook the testing of glass Sikes hydrometers (about 50 years ago) the instruments were compared with metal Sikes hydrometers under conditions of artificial Laboratory cleanness, such that the liquid menisci were always strongly developed, not only around the stem of the glass instrument, but also around the metal stem, even in solutions of great dilution. Hence, though the glass and metal instruments agreed at the Laboratory, they disagreed considerably in service. But when in later years it was found that the basis used for verification was of questionable validity for practical circumstances, the basis was not changed because very dilute solutions were of little concern and, no precise reference conditions could then be arrived at for metal hydrometers, it was inappropriate to lay down such conditions for glass instruments. In these circumstances it was thought that it would be best to preserve the continuity of the standard. However, now that reference surface tensions and degree of wetness of stems have been laid down for metal instruments, advantage has been taken of the possibility of remedying the situation. The hydrometer manufacturers have already been notified.

Acknowledgment

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Table 5. *Specific gravities corresponding to readings on glass Sikes hydrometers (standard temperature 51° F), immersed in liquid having the given surface tension*

Indication		Sp. gr. 60/60° F (true, not "in air")	Surface tension (dyn/cm)
*	†		
B 0	A 0	0.78307	21.8
B 5	A 5	0.79111	22.5
B10	A10	0.79933	23.1
A 0	A10	0.79933	23.1
A 5	A15	0.80754	23.6
A10	A20	0.81590	24.0
0		0.81590	24.0
5		0.82431	24.4
10		0.83280	24.8
15		0.84127	25.2
20		0.84994	25.6
25		0.85859	26.0
30		0.86745	26.4
35		0.87629	26.8
40		0.88530	27.2
45		0.89431	27.6
50		0.90351	28.0
55		0.91270	28.5
60		0.92208	29.1
65		0.93144	29.8
70		0.94106	30.5
75		0.95067	32
80		0.96042	35
85		0.97016	40
90		0.98009	45
95		0.99001	50
100		1.00015	55

* British nomenclature.

† Indian nomenclature.

A time-resolved spectrograph for use with triggered light sources

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Abstract

Details are given of a time-resolved spectrograph with rotating speeds up to $5\text{ mm}/\mu\text{s}$ (at $f/12$) which can be used to view weak light sources. The main limitation is that the light source must be able to be triggered reproducibly. This is necessary as the increased effective light intensity needed to obtain a usable image density in the camera of the spectrograph is produced by the accurate superposition of the light of many discharges.

An experiment is described which shows that the superposition of fifty successive discharges has been achieved with an overall variation of less than $0.3\ \mu\text{s}$.

Introduction

ELECTRICAL discharges used to produce high temperature plasmas for the study of controlled thermonuclear fusion have often a time scale of microseconds. For example, the z-pinch discharge at Imperial College (Curzon 1959, Curzon *et al.* 1960) has a pinch-time of 10 to $100\ \mu\text{s}$, and is reproducible until just after the first pinch. One can study the spectral emission of such a light source by one of three methods:

(a) a monochromator and a photomultiplier, (b) a very fast open-close shutter and a spectrograph, (c) a time-resolved spectrograph.

Method (a) which is often used, gives the complete time variation but can deal only with one wavelength per discharge. Method (b) gives the full range of wavelengths but only at a single instant during the discharge cycle. Method (c) provides the complete time variation over a wide range of wavelengths for the whole of the discharge cycle.

A time-resolved spectrograph clearly has several advantages, particularly when a time-resolved spectrum of a single shot of a non-reproducible discharge is taken (Gabriel 1960). However, it is not always possible to obtain a single shot photograph of the whole spectrum, because the light intensity is too low. This applies in particular to the early stages of the discharge.

If the discharge is reproducible and can be accurately triggered, then it would be possible to obtain a time-resolved spectrum of even the early stages by superposing the light of many successive discharges on the same photographic plate.

This paper describes apparatus built at Imperial College, London, to superpose time-resolved spectra to within a fraction of a microsecond. An experiment is given using the light from a simple triggered spark gap to test its performance.

The time-resolved spectrograph

Time resolution is achieved by using a high speed rotating mirror as designed at the Atomic Weapons Research Establishment, Aldermaston. A 1000 c/s generator supplies power to the induction motor of the rotating mirror and has an adjustable voltage amplitude.

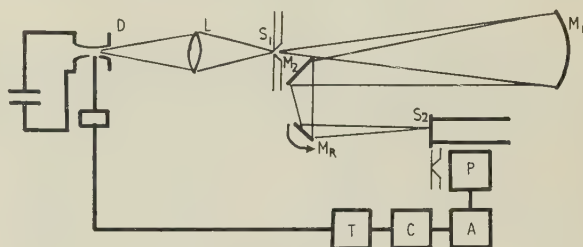


Fig. 1. Experimental arrangement.

P, photomultiplier; C, control unit; A, amplifier; T, triggering unit.

Figure 1 shows diagrammatically the experimental set-up. Light from the transient discharge D is focused on the slit S_1 . The slit S_1 is focused via the concave mirror M_1 , the plain mirror M_2 and the rotating mirror M_R on the slit S_2 , which is the entrance slit of a Hilger medium quartz spectrograph. Not shown in the diagram is the direct current lamp which reflects from the rotating mirror on to the photomultiplier P, so causing a sharp pulse output every half-revolution of the mirror.

In an actual experimental run the light source is first charged and set ready for firing. The rotating mirror is switched on and the pulses from the photomultiplier fed into the control unit (see Fig. 1). When the mirror reaches the preset speed, the control unit automatically fires the discharge such that an image is cast on the slit S_2 . The operator has only to switch off the mirror, re-charge the light source and repeat, to obtain a second image superimposed on the first.

A block diagram of the control unit is shown in Fig. 2.

Consider, as in Fig. 3, three successive photomultiplier pulses A, B, C arriving at the control unit. Pulse A passes through the paralysis unit and the blocking unit and sets the Miller time-base in operation. The pick-off unit gives a pulse output E when the time-base has run down to a preset voltage, that is at a fixed time interval τ after the firing of the time-base unit. This pulse is fed after shaping, into one side of the first coincidence unit and if the second pulse from the photomultiplier, pulse B, arrives at the same time, then the coincidence gate is fired. As the first coincidence gate fires, the first thyratron unit fires and holds down one side

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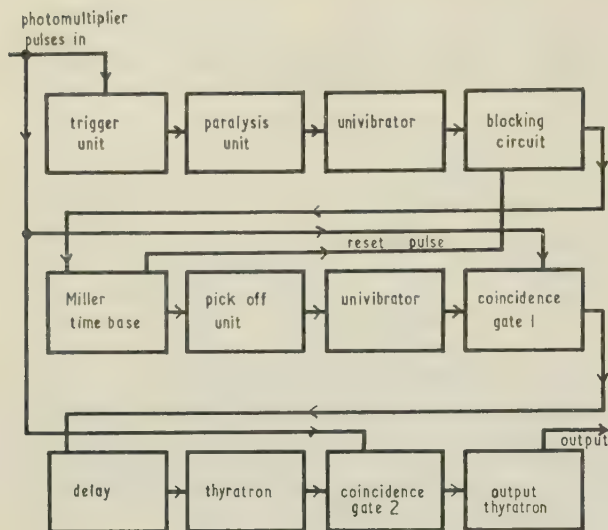


Fig. 2. The control unit.

of the second coincidence gate. Then the third pulse from the photomultiplier, pulse C, passes directly through the second coincidence gate and fires the output thyatron giving a very sharp positive pulse which can be used to fire the

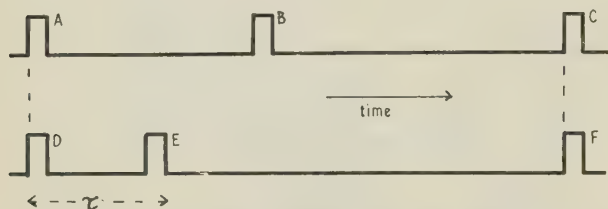


Fig. 3. Successive pulses in the control unit.

triggered light source. Thus the control unit can measure very accurately the speed of rotation of the mirror, since the half-period is τ and in addition will fire the discharge when the mirror is in a known position, i.e. at the instant the mirror reflects light into the photomultiplier.

It is convenient to obtain time-resolved spectra by starting the sequence with the rotating mirror at rest or rotating slowly. Then in Fig. 3, it can be seen that as the mirror accelerates, pulse B approaches the delayed pulse E, as shown, and coincidence occurs when the leading edge of B meets the trailing edge of E. The time delay τ can be varied from 0.5 to 10 ms, and with such a time interval one finds experimentally a jitter of up to 10 μ s on the pulse E. This means that although the speed of rotation of the mirror is determined to better than 1%, the time of firing of the first coincidence gate has a variation of up to 10 μ s. Therefore, it would be most unsuitable to fire the discharge directly from the first coincidence gate. However, the total delay in the triggering unit is approximately 10 μ s and as indicated in Fig. 1, the mirror reflects light into the photomultiplier just 10 μ s before it is in a suitable position to reflect the discharge light into the spectrograph. Therefore, the error in superposition caused by the 1% error in the mirror speed, is just 1% of 10 μ s which is 0.1 μ s.

Another source of error is that the rotating mirror is accelerating. The speed of rotation is measured over one half-cycle and the pulse arriving at the end of the next half-

cycle is used to fire the discharge. The acceleration and speed of the rotating mirror are limited by the voltage amplitude and frequency of the supply generator, respectively. Therefore, by suitable control of the voltage amplitude the 1000 c/s power supply the acceleration of the mirror can be arranged to be below a certain limit as it approaches the operating speed. In practice, the acceleration has been determined by measuring the velocity of the pulse B, in Fig. 2, across the screen of a cathode-ray oscillograph, the oscillograph being triggered by the pulse A. The pulse B moved at the rate of 1 ms in 10 s at the time of firing, and this was very consistent, certainly to within 10%. Then working at a half period of 2.5 ms because of the acceleration the next half period will be less than 2.5 ms (2.5×10^{-3}) (0.1×10^{-3}) = 0.25 μ s.

This amounts to an error in the velocity of much less than 1% and as such, will cause an error in the superposition of spectra of much less than 0.1 μ s.

The last possible sources of error are the actual fluctuations on the leading edge of the output pulse of the control unit and in the delay of the triggering unit. Both of these have been checked with a Tektronix 545 oscilloscope (Tektronix Inc., Portland, U.S.A.); the delay in the triggering unit is constant to within 0.02 μ s and the error on the photomultiplier pulses is better than 0.2 μ s.

Therefore, one would expect this time-resolved spectrograph to be capable of superposing time-resolved spectra within 0.2 μ s.

Experimental results

To show experimentally that the time-resolved spectrograph does in fact achieve the superposition of spectra, a complete system was tested using as a transient light source a triggered spark gap working in air. The spark gap had stainless steel electrodes and was connected across a 10 μ F capacitor bank. The capacitors were charged to 5 kv which was arranged to be just below the breakdown potential of the spark gap. The trigger pin, which was located in the earthy electrode of the spark gap, could be pulsed to -12 kv by the triggering unit, so causing immediate breakdown of the gap. Figure 4 shows the current profile of the spark gap, and below it the intensity profile of the line N II (12) 3994.9 Å as recorded on a 1P28 photomultiplier used in conjunction with a Hilger medium quartz spectrograph.

As indicated in Fig. 4 the first two half-cycles of the discharge of the spark gap take $14 \pm 0.6 \mu$ s and so to photograph them with the time-resolved spectrograph, which has a slit length of 18 mm, the writing speed must be about 1 mm/ μ s. The numerical aperture of the spectrograph is 13.8, therefore to fill it with light the rotating mirror must be about 35.5 cm from the entrance slit. The distance between the rotating mirror and the entrance slit was measured as 37.5 ± 0.5 cm so that with a half-period of 2.5 ± 0.5 ms the writing speed was 0.94 ± 0.04 mm/ μ s.

The experimental procedure was to charge the capacitor bank to 5 kv having first set the control unit. Then switch on the 1000 c/s supply to the rotating mirror, and once the mirror had begun to turn, switch on the d.c. lamp which reflects into the photomultiplier. The lamp has to be switched on when the mirror is already turning because at very low speeds the photomultiplier output becomes so low that the first coincidence gate in the control unit is automatically fired. By repeating this procedure 50 times, the light from 50 successive discharges was superimposed in the spectrograph.

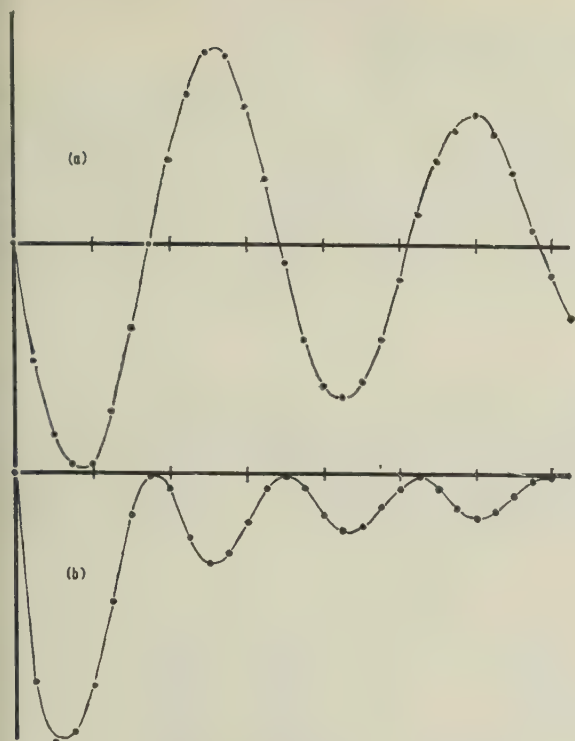


Fig. 4. Oscilloscope traces.

(a) Current in the spark gap; (b) light intensity at 3994.9 Å.
Scale 4.1 μs per div.

Figure 5 shows the fifty superposed time-resolved spectra of the first two half-cycles of the discharge. The strong line which appears on the approximate wavelength scale at 4015 Å is in fact N II (12) line, 3994.9 Å. A single shot profile of the line has already been obtained using a photomultiplier (Fig. 4(b)). This profile is compared in Fig. 6 with the multi-shot profile as determined by microphotometering the photographic plate, and converting to incident light intensity, assuming a linear plate characteristic.

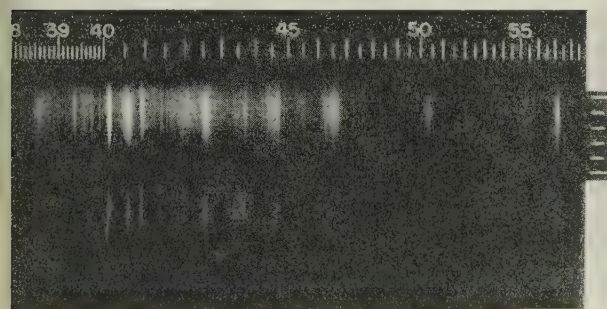


Fig. 5. A time-resolved spectrum.

Side-scale 1.1 μs per div.

Because of the non-linearity of the plate characteristic at low intensity the minimum of the multi-shot intensity profile at $\phi = \pi$, would in fact be less than 0.15 which is the value

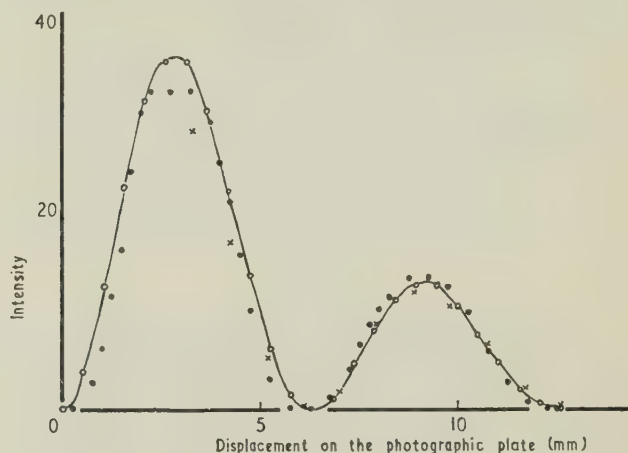


Fig. 6. The intensity profile at 3994.9 Å.

● microphotometer profile;
× photomultiplier profile;
○ ideal case. $I = I_0(1 - \cos 2\phi) \exp(-\phi/\alpha)$.

determined by assuming a completely linear characteristic. The third curve shown in Fig. 6, $I = I_0(1 - \cos 2\phi) \exp(-\phi/\alpha)$, represents the ideal case, with perfect superposition. The value of α was calculated from the first two maxima of the photomultiplier profile, while I_0 was chosen to match the microphotometer intensity profile at its first maximum. Assuming there is an overall error in the superposition of spectra of $\delta \mu\text{s}$ and there is equal probability of individual errors occurring over the whole range δ , then it can be shown that the expected intensity at the first minimum, $\phi = \pi$, when fifty discharges are superposed is

$$(I_{\text{exp}})_{\pi} = 13.9 \delta^2.$$

From this relation the error in superposition has been calculated as $\delta = 0.3 \mu\text{s}$ taking the minimum of I_{exp} as 0.15.

Acknowledgments

The authors wish to thank Dr. Latham and all the members of the High Temperature Physics group at Imperial College for the many useful discussions that have taken place. One of the authors thanks the Department of Scientific and Industrial Research for the maintenance grant he has received during the course of this work.

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Pulse-sampling voltmeter and its application to transistor testing

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Abstract

A pulse-sampling voltmeter designed for measuring low-frequency transistor current gain under large signal conditions is described. The method consists of sampling a waveform at approximately 100 c/s with a 20 μ s pulse, which gates the voltage under test at any required point of the cycle. The segment selected by the pulse is amplified and rectified, its amplitude being determined by a comparison technique in which a variable d.c. voltage is fed to the test set in place of the waveform. The equipment presents an input resistance of at least 200 k Ω on all ranges and measures voltages from 100 mV to 75 V with an accuracy to 1%; the upper limit could be extended.

1. Introduction

THIS voltmeter was developed to measure transistor current gain under large signal conditions when electrode currents and inter-electrode voltages vary widely. The usual method of measuring current gain by small signal injection will yield values at any required d.c. operating point. It is, however, unsuitable for determining variations in current gain during large signal operation, because of the difference in collector dissipation under static and dynamic conditions. The same objection applies to another method of measuring current gain in which the signal consists of narrow pulses, which cause negligible change in mean collector dissipation. With the present method the current gain is determined under actual operating conditions at any desired part of the cycle.

2. Principle of operation

The periodic voltage under test is applied to the voltmeter and a narrow portion ab (Fig. 1) is gated for measurement. Referring to Figs 1 to 3, the test voltage is applied to the control grid and a narrow positive-going gating pulse, which

can be adjusted to any part of the cycle, is applied to the suppressor grid of V_5 , a dual control pentode amplifier. The gating pulse is derived from the source driving the equipment under test, thereby ensuring a steady position of gating pulse relative to test voltage. The inevitable pulses appearing

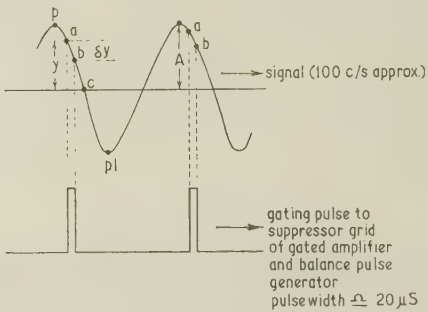


Fig. 1. Gating action.

at the anode of V_5 in the absence of an input voltage at the control grid, due to the switching action at the suppressor grid, are balanced out by the arrangement shown in Fig. 2.

The magnitude and polarity of the output pulses at the anode of V_5 are then determined by the value of the test voltage at the time of gating. The output pulses are amplified and rectified so that the d.c. current in the terminating meter depends in amplitude and polarity on the gated segment of the signal. Amplitude and polarity of ab are determined by the substitution of a d.c. voltage; the peak amplitude of the gated segment clearly equals the d.c. voltage.

The width of the gating pulse was chosen so that amplitude variations over the interval ab of the gated signal are small. The pulse width is 20 μ s and the operating frequency about 100 c/s, so that the pulse width is 1/500 of a cycle. Fixing the maximum tolerable value of $\delta y/y$ in Fig. 1 at 0.1, we find

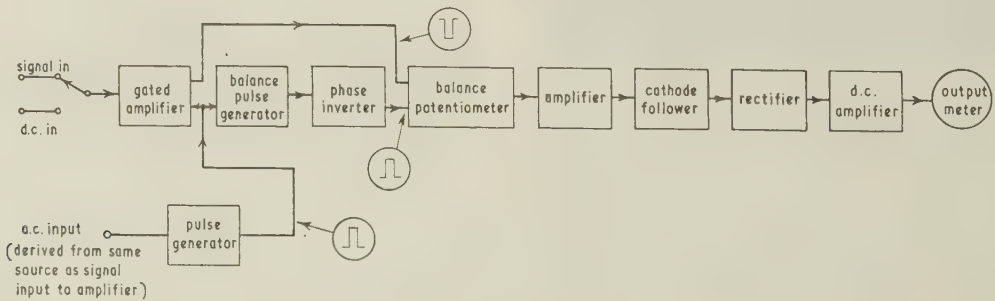


Fig. 2. Block diagram.

A to be 0.12, i.e. useful measurements may be made down about one-tenth of the peak amplitude.

3. Circuit description

The circuit diagram is shown in Fig. 3. Stages V_1 to V_4 form the pulse generator, V_1 being an amplifier, V_2 and V_3 quaring valves and V_4 a pulse amplifier, the narrow pulse having been produced by the differentiating action of C_9 and R_{14} . The position at which the pulse gates the signal is adjusted by RV_1 and RV_2 which, together with C_1 , constitute a phase-shift network covering a range of 180° . A further range of 180° is effected by S_1 , permitting overall phase

changes up to 360° . An a.c. input of 5 v r.m.s. or larger is required to produce a pulse with sharp leading and trailing edges.

The gating pulse is applied to the suppressor grid of V_5 and V_6 , thereby allowing the signal at the control grid of V_5 to pass to the anode. V_6 and the phase inverter V_7 produce a positive-going pulse which cancels the pulse appearing at the anode of V_5 in the absence of a signal, RV_3 being the balancing control. The signal level is adjusted by S_3 (coarse) and S_4 (fine); switched gain control was preferred to a potentiometer in order to avoid difficulties arising from irregular contact pressure between track and wiper. The width of the pulse at the anode of V_5 depends slightly on the grid-

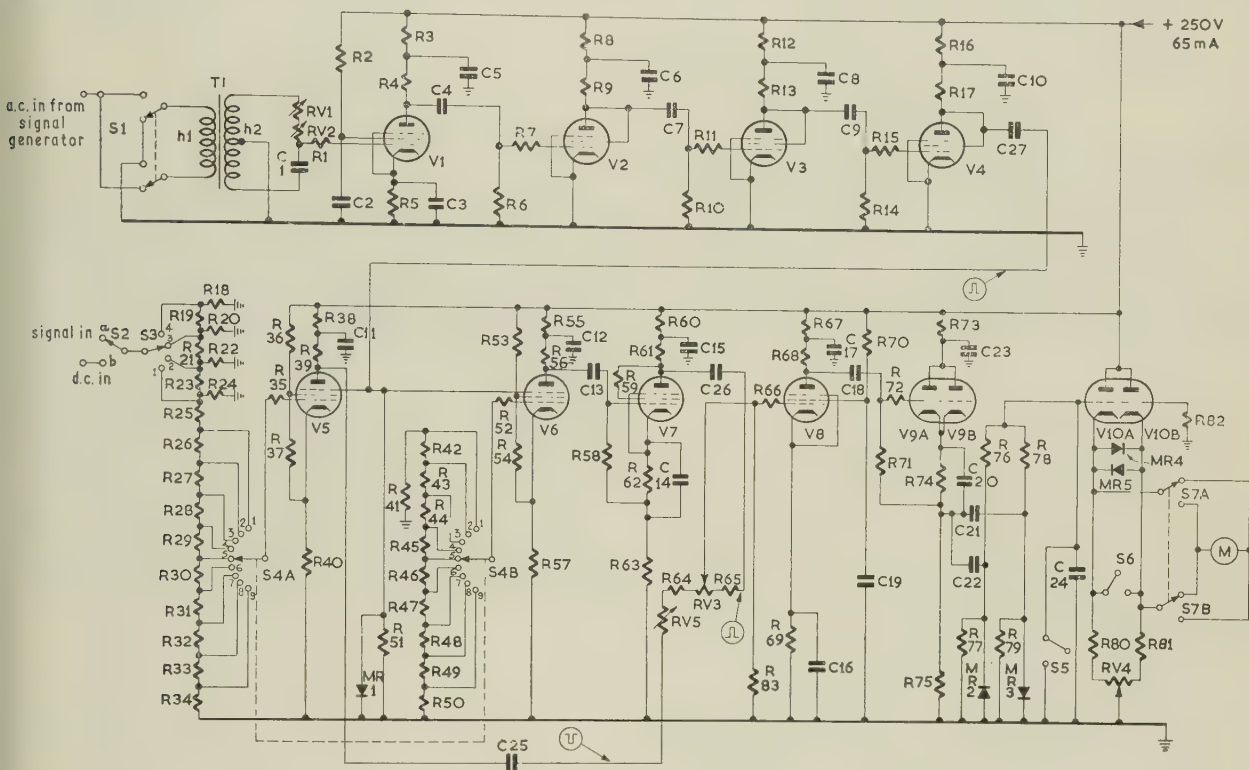


Fig. 3. Circuit diagram

$R_1 = 270 \text{ k}\Omega$
 $R_2 = 100 \text{ k}\Omega$
 $R_3 = 2.2 \text{ k}\Omega$
 $R_4 = 22 \text{ k}\Omega$
 $R_5 = 1 \text{ k}\Omega$
 $R_6 = 1 \text{ M}\Omega$
 $R_7 = 1 \text{ M}\Omega$
 $R_8 = 2.2 \text{ k}\Omega$
 $R_9 = 10 \text{ k}\Omega$
 $R_{10} = 1 \text{ M}\Omega$
 $R_{11} = 1 \text{ M}\Omega$
 $R_{12} = 2.2 \text{ k}\Omega$
 $R_{13} = 10 \text{ k}\Omega$
 $R_{14} = 47 \text{ k}\Omega$
 $R_{15} = 470 \Omega$
 $R_{16} = 2.2 \text{ k}\Omega$
 $R_{17} = 10 \text{ k}\Omega$
 $R_{18} = 390 \text{ k}\Omega$
 $R_{19} = 1.5 \text{ M}\Omega$
 $R_{20} = 390 \text{ k}\Omega$
 $R_{21} = 1.5 \text{ M}\Omega$
 $R_{22} = 390 \text{ k}\Omega$
 $R_{23} = 1.5 \text{ M}\Omega$
 $R_{24} = 390 \text{ k}\Omega$
 $R_{25} = 270 \text{ k}\Omega$
 $R_{26} = 56 \text{ k}\Omega$
 $R_{27} = 56 \text{ k}\Omega$
 $R_{28} = 56 \text{ k}\Omega$
 $R_{29} = 56 \text{ k}\Omega$
 $R_{30} = 56 \text{ k}\Omega$
 $R_{31} = 56 \text{ k}\Omega$
 $R_{32} = 56 \text{ k}\Omega$
 $R_{33} = 56 \text{ k}\Omega$
 $R_{34} = 56 \text{ k}\Omega$

$R_{35} = 2.2 \text{ k}\Omega$
 $R_{36} = 82 \text{ k}\Omega$
 $R_{37} = 82 \text{ k}\Omega$
 $R_{38} = 15 \text{ k}\Omega$
 $R_{39} = 3.3 \text{ k}\Omega$
 $R_{40} = 180 \Omega$
 $R_{41} = 180 \text{ k}\Omega$
 $R_{42} = 56 \text{ k}\Omega$
 $R_{43} = 56 \text{ k}\Omega$
 $R_{44} = 56 \text{ k}\Omega$
 $R_{45} = 56 \text{ k}\Omega$
 $R_{46} = 56 \text{ k}\Omega$
 $R_{47} = 56 \text{ k}\Omega$
 $R_{48} = 56 \text{ k}\Omega$
 $R_{49} = 56 \text{ k}\Omega$
 $R_{50} = 56 \text{ k}\Omega$
 $R_{51} = 1 \text{ M}\Omega$
 $R_{52} = 2.4 \text{ k}\Omega$
 $R_{53} = 82 \text{ k}\Omega$
 $R_{54} = 82 \text{ k}\Omega$
 $R_{55} = 15 \text{ k}\Omega$
 $R_{56} = 3.3 \text{ k}\Omega$
 $R_{57} = 180 \Omega$
 $R_{58} = 1 \text{ M}\Omega$
 $R_{59} = 100 \Omega$
 $R_{60} = 3.3 \text{ k}\Omega$
 $R_{61} = 8.2 \text{ k}\Omega$
 $R_{62} = 180 \Omega$
 $R_{63} = 8.2 \text{ k}\Omega$
 $R_{64} = 220 \text{ k}\Omega$
 $R_{65} = 220 \text{ k}\Omega$
 $R_{66} = 2.2 \text{ k}\Omega$
 $R_{67} = 3.3 \text{ k}\Omega$
 $R_{68} = 15 \text{ k}\Omega$

$R_{69} = 180 \Omega$
 $R_{70} = 82 \text{ k}\Omega$
 $R_{71} = 2.2 \text{ M}\Omega$
 $R_{72} = 470 \Omega$
 $R_{73} = 12 \text{ k}\Omega$
 $R_{74} = 150 \Omega$
 $R_{75} = 3.3 \text{ k}\Omega$
 $R_{76} = 2.2 \text{ M}\Omega$
 $R_{77} = 1 \text{ M}\Omega$
 $R_{78} = 2.2 \text{ M}\Omega$
 $R_{79} = 1 \text{ M}\Omega$
 $R_{80} = 1 \text{ k}\Omega$
 $R_{81} = 1 \text{ k}\Omega$
 $R_{82} = 1 \text{ M}\Omega$
 $R_{83} = 1.5 \text{ M}\Omega$

$RV_1 = 10 \text{ k}\Omega$
 $RV_2 = 100 \text{ k}\Omega$
 $RV_3 = 50 \text{ k}\Omega$
 $RV_4 = 1 \text{ k}\Omega$
 $RV_5 = 5 \text{ k}\Omega$

$C_1 = 0.5 \mu\text{F}$
 $C_2 = 4 \mu\text{F}$
 $C_3 = 25 \mu\text{F}$
 $C_4 = 0.1 \mu\text{F}$
 $C_5 = 8 \mu\text{F}$
 $C_6 = 8 \mu\text{F}$
 $C_7 = 0.1 \mu\text{F}$
 $C_8 = 8 \mu\text{F}$
 $C_9 = 15 \mu\text{F}$
 $C_{10} = 8 \mu\text{F}$
 $C_{11} = 8 \mu\text{F}$
 $C_{12} = 8 \mu\text{F}$

$C_{13} = 0.1 \mu\text{F}$
 $C_{14} = 25 \mu\text{F}$
 $C_{15} = 8 \mu\text{F}$
 $C_{16} = 25 \mu\text{F}$
 $C_{17} = 32 \mu\text{F}$
 $C_{18} = 0.1 \mu\text{F}$
 $C_{19} = 8 \mu\text{F}$
 $C_{20} = 25 \mu\text{F}$
 $C_{21} = 1 \mu\text{F}$
 $C_{22} = 1 \mu\text{F}$
 $C_{23} = 32 \mu\text{F}$
 $C_{24} = 0.5 \mu\text{F}$
 $C_{25} = 0.5 \mu\text{F}$
 $C_{26} = 0.5 \mu\text{F}$
 $C_{27} = 0.1 \mu\text{F}$

$V_1 = 6\text{F}12$
 $V_2 = 6\text{F}12$
 $V_3 = 6\text{F}12$
 $V_4 = 6\text{F}12$
 $V_5 = 6\text{F}33$
 $V_6 = 6\text{F}33$
 $V_7 = 6\text{F}12$
 $V_8 = 6\text{F}12$
 $V_9 = 12\text{A}7$
 $V_{10} = 12\text{A}7$

$MR_1, MR_2, MR_3 = 0\text{A}10$
 $MR_4, MR_5 = 5\text{X}642$
 T_1 Mullard ferroxcube LA13
 $n1: 800 \text{ T}, n2: 400\text{T} + 400\text{T}$
 No. 36 s.w.g. E.C. wire
 M 250 μA meter

cathode resistance and S_4 maintains grid-cathode resistances of V_5 and V_6 approximately equal, to ensure identical pulse widths of the outputs of V_5 and V_6 at all gain control settings. V_5 has to amplify a.c. and d.c. equally up to the suppressor electrode. Hence screen and cathode by-pass capacitors must be omitted and positive feedback is applied from screen to cathode via R_{37} to increase the stage gain.

The pulses are amplified by V_8 and fed via the cathode follower V_9 to the rectifiers MR_2 and MR_3 . The action of these rectifiers is illustrated in Fig. 4 in which the component



Fig. 4. Rectification.

labelling conforms with Fig. 3. The d.c. output voltage at A will very nearly equal the peak amplitude of the pulse, while the d.c. output voltage at the junction C_{22} and R_{77} of Fig. 3 will be very nearly zero. The two outputs are combined, resulting in a d.c. voltage which is very nearly equal to the amplitude of the pulse and whose polarity depends on that of the pulse. V_{10} is a d.c. amplifier feeding the output meter M, which is shunted by silicon diodes protecting it against overload.

4. Operating procedure

After the equipment has been running for a few minutes, RV_4 (Fig. 3) is adjusted to give zero current through the output meter with S_5 closed. S_5 is opened and S_2 is switched to position a. With the phase controls RV_1 and RV_2 set to any suitable position, the gain controls S_3 and S_4 are adjusted to give a convenient output reading.

RV_3 and RV_5 are then adjusted to give zero output for zero signal input; this adjustment depends on the gain control setting and is made with S_2 in position b and with the d.c. voltage set to zero. (The d.c. voltage supply, including its voltmeter, is straightforward and is not shown.) The gated segment is now measured accurately by adjusting the d.c. voltage to obtain the same output for both positions of S_2 .

In practice suitable positions for the phase control are found by obtaining an output approximately equal to that given by a pre-set d.c. voltage.

5. Performance

The range sensitivities are given in the Table below, together with the 'maximum' generator resistance, which is defined as the value where the zero setting changes by 1% of full-scale deflection relative to the setting with zero generator resistance. This limitation, which is due to a breakthrough of the switching pulse from suppressor to control grid in the gated amplifier valve, could be overcome

Range sensitivity and maximum generator resistance

Position of S_3 (Fig. 3)	1	1	2	3	4
Position of S_4 (Fig. 3)	1	9	1	1	1
Input voltage for full-scale deflection (v)	0.13	0.73	1.7	12	75
Maximum generator resistance (k Ω)	2.0	40	250	∞	∞

by interposing a d.c. amplifier between S_2 and S_3 of Fig. 3. This step was, however, omitted, since the maximum generator resistance is sufficiently high for most transistor applications.

Errors due to differences between a.c. and d.c. source resistances at S_2 in Fig. 3 are negligible for values below 2 k Ω ; for higher values the required matching is readily obtained by adjusting the d.c. supply circuit.

The accuracy of the voltmeter was assessed by measuring V_1 and V_2 in Fig. 5 where R_1 and R_2 were nominal 1 M Ω resistors selected such that $(R_1 + R_2)/R_2$ equalled 2.0.

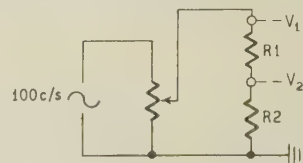


Fig. 5. Test circuit.

Tests were made by taking the mean of four readings for each measurement; this procedure is adhered to generally. V_1/V_2 was found to lie between 1.98 and 2.01 in measurements in which V_1 ranged from 220 mv to 9 v and whose gated segment amplitudes extended from 100 mv to 9 v as down to one-tenth of the peak amplitude. Furthermore, when the pulse was set to gate the peak of the a.c. input (p or p' in Fig. 1) the d.c. comparison voltage agreed with the reading of a calibrated voltmeter measuring V_1 to within the accuracy ($\pm 1\%$) of that instrument. It is concluded that the ratio of two voltages is determined accurately to $\pm 2\%$ when each value is the mean of four readings.

A further performance evaluation was made by using the voltmeter to obtain the dynamic amplifier characteristic in Fig. 6 for the common emitter amplifier shown in Fig. 7. The harmonic margins of V_0 were measured with a wave-

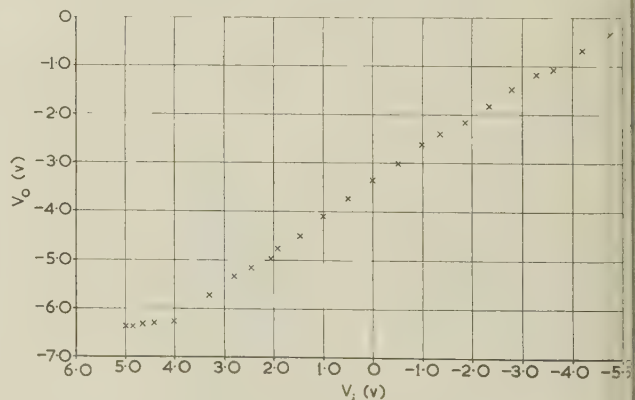


Fig. 6. Amplifier characteristic.

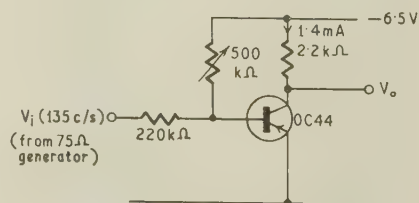


Fig. 7. Transistor amplifier circuit.

alyser and compared with values calculated by fitting a polynomial to the characteristic.

The most suitable numerical technique is to fit a finite Chebyshev series to the experimental points by the method of least squares. The resultant set of simultaneous equations has large diagonal coefficients and forms a 'well-conditioned' set, solvable readily by relaxation. Numerical values of the coefficients then yield the desired margins directly. Such a computation is a task suitable for a digital computer and programmes are currently available on several computers.

Calculated and measured second harmonic margins were 35 dB and 37 dB respectively; the corresponding figures for the third harmonic were 24 dB and 23 dB. The good agreement confirms that measurements may be made with considerable accuracy.

6. Applications

The basic test circuit for measuring common emitter current gain is shown in Fig. 8. The current gain is given by $R_1/V_g R_c$, where R_c , the effective collector load, equals $R_3/(R_2 + R_3)$, and where V_g and V_c are the amplitudes of the gated segments. The above formula holds provided $V_g \gg V_b$, a condition which is fulfilled by making R_1 sufficiently large. R_1 is chosen to keep the second harmonic distortion of i_b due to non-linearity of the i_b/v_b characteristic small. R_c is usually made equal to the optimum load for class A power amplification and has values between several

hundred and several thousand ohms. These magnitudes are generally well below the maximum permissible generator resistance quoted previously, bearing in mind that gated

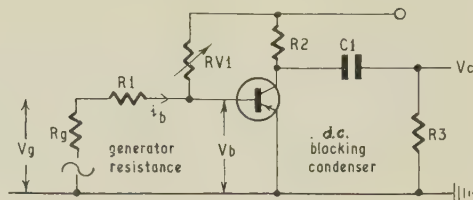


Fig. 8. Transistor test circuit.

segment amplitudes exceed one-tenth of the peak a.c. swing which will be several volts.

The voltmeter was primarily designed for measuring transistor current gain under large signal operating conditions. It is, however, suitable for the investigation of low-frequency waveforms in general.

Acknowledgment

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An instrument to sharpen microtome knives

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Abstract

This instrument was designed to save the time spent in sharpening microtome knives by hand. It sharpens by simultaneous backwards and forwards and side to side movements of the knife over an abrasive plate. The movement is derived from an electric motor. The whole instrument is portable and requires no attention except to turn the knife over periodically. An adjustable steel toe allows the facet angle of the knife edge to be correctly set. This disposes of the dangerous operation of fitting to the knife the split cylindrical backing piece supplied by the knife-makers for this purpose. In order that the knife shall not be subjected to the stresses of clamping it is held in position on the abrasive surface by cylindrical permanent magnets, which also act in keeping the knife edge in contact with the abrasive surface with an even constant pressure. The use of magnets also facilitates the placing of the knife in its position for sharpening and its removal therefrom. It is shown that the repeated examination of the edge of the knife by microscope during sharpening is necessary.

Introduction

THE present instrument was designed and made in response to a request for something which would save much time spent in hand sharpening of knives. It was required that the instrument should be capable of satisfactory use without special skill and that the results should be not inferior to those of hand sharpening, and also that if possible it should be portable. This has been achieved.

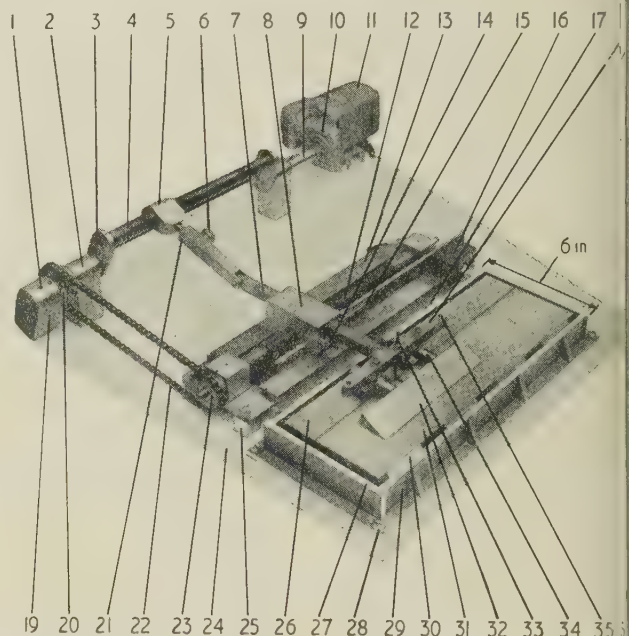
It is generally recognized that the sharpening of a knife by a machine which merely moves it backwards and forwards on a stone or other form of hone does not produce an edge comparable with that of honing by hand. More is required than a simple reciprocating movement as can be seen by microscopic examination of the edges of knives. In manual sharpening the facet angle of the blade is determined by a backing piece, and its movement is in one plane but is not a linear one backwards and forwards. Side to side and sometimes rotary movements are also made. This new instrument imparts to the knife a side to side movement together with a backward and forward movement. The repeated examination of the edge by microscope during sharpening is necessary.

Principle and design

The general construction and method of operation of the instrument is illustrated in the Figure.

It has an electric drive and requires no attention after the initial setting, except to turn the knife over periodically. The knife requires no backing piece. Instead, an adjustable steel toe (33) determines the facet angle of the blade.

To prevent the knife from receiving clamping stresses it is held in position solely by two cylindrical permanent magnets. Only the top edges of the forward faces of these magnets make contact with the back of the knife blade. To accomplish



General view of instrument showing microtome knife being sharpened.

- | | |
|--|--|
| 1. 4 BA steel lock screws. | 19. Brass counter-balancing weight. |
| 2. Brass bearing block. | 20. Driving sprocket. |
| 3. Brass crank plate. | 21. $\frac{1}{4}$ in. square brass connecting rod. |
| 4. Steel screwed rod $\frac{1}{2}$ in. B.S.W. | 22. Chain 8 mm pitch. |
| 5. Brass nut. | 23. Driven sprocket. |
| 6. 4 BA brass thumb screw. | 24. $\frac{1}{4}$ in. thick hinged steel plate. |
| 7. $\frac{1}{2}$ in. square piston rod. | 25. Metal support blocks. |
| 8. Brass travelling block. | 26. Ground steel distance piece. |
| 9. Steel coupling. | 27. 4 BA tapped holes. |
| 10. Gear box. | 28. Screws brass 2 BA. |
| 11. Electric motor. | 29. Duralumin box. |
| 12. Steel screwed rod $\frac{1}{2}$ in. B.S.W. | 30. Duralumin vice jaws. |
| 13. Brass slide. | 31. 'Arkansas' oil stone. |
| 14. 4 BA brass thumb screws. | 32. Microtome knife. |
| 15. Steel rod $\frac{1}{4}$ in. diam. | 33. $\frac{1}{4}$ in. diam. silver steel hardened. |
| 16. Ebonite switch cover. | 34. $\frac{1}{2}$ in. diam. permanent bar magnet. |
| 17. Steel set screws $\frac{1}{4}$ in. B.S.W. | 35. 2 BA clearing holes. |
| 18. $\frac{1}{2}$ in. square brass. | |

this the faces are ground to make an angle of 30° with the vertical. The resulting wedge-shaped gap between each magnet and the knife ensures that the cutting edge is held down on to the hone with a slight constant pressure. This is an important feature. To impose greater pressure, when necessary, additional small magnets are placed on top of the knife.

For the first stage of sharpening an oiled 'Arkansas' stone is used and for the second a glass plate 0.25 in. thick is placed on top of the stone and covered with soap solution.

the trolley on which the whole instrument is carried is fitted with a means of tilting the whole instrument platform, so that the oil or soap solution is returned after being pushed forward by the knife. If a knife edge requires considerable preliminary grinding an additional glass plate treated with carborundum powder can be fitted on top of the stone for that purpose.

In order to accommodate long and short knives, the instrument is provided with two adjustable steel rods (15) which push and pull the flick-over lever of the switch for reversing the motor, and thereby determine the extent of the slide to side travel of the knife.

One cannot over-stress the importance of a microscope (magnification 100 diameters) as an aid to sharpening. From knowledge obtained by comparing edges that are satisfactory in practice with those that are not one is able to decide when, in sharpening, the desired edge has been obtained.

Construction

The driving mechanism consists of a fractional-horsepower double-reduction motor (11) of 220–240 v, torque 30 lb/in., with a final spindle speed of 10 rev/min, a coupling (9) connects the gear box (10) spindle to the screwed crank (4), the size and pitch of the screw is identical with the screwed rod (12) of the slide (13), thus the movement of carrier nut (5) and the traveller (8) are kept in alignment. The stroke of the crank is 2.875 in.

The reversing switch (16) is lever operated and is screwed to the slide (13) and covered with an ebonite box.

A clear Perspex cover, not shown in position on the photograph, is placed over the working mechanism when in use or at rest; a portion of the cover is hinged to allow access for easy removal of the knife.

Performance

Further materials (not shown in the photograph) necessary for the successful sharpening of microtome knives, are three

pieces of glass plate, the same size as the inside area of the box; various grades of carborundum powders, lubricating oil and a neutral soap solution.

If the knife to be sharpened has a badly serrated edge it will have to be rubbed, first on one facet, and then the other, using a glass plate with diminishing grades of abrasive until the serrations disappear and the edge is straight, but it will be understood that if the knife edge requires only honing, a clean glass plate with a neutral soap solution as lubricant would meet this requirement. In general practice it has been found that rubbing the knife facets first on an 'Arkansas' oil stone and then on a glass plate is all that is necessary to produce a perfect result.

In beginning the sharpening of a microtome knife the angle of the two facets can be obtained with the help of an adjustable workshop protractor or angle gauge applied to the knife when lying on a flat surface. This angle can be reproduced when the knife is lying on the glass plate or oil stone of the instrument by adjustment of the steel toe, which engages the under side of the knife back and is centrally disposed along its length. The upper collar on the vertical shaft of the steel toe limits its excursion downwards, and the lower collar upwards, thus any difference in the heights of the upper surfaces of the oil stone and the glass plate can be compensated for by adjustment of the toe.

Much has been written on the sharpening of microtome knives by hand but the only effective test is whether the knife cuts the material properly. With the present instrument and a microscope it has been found that without previous experience in this field, laboratory staff can produce excellent results quickly and efficiently. The instrument has been in constant use for the last twelve months.

Acknowledgments

I wish to express my thanks to Professor J. M. Peterson and Dr. S. L. Stone for helpful suggestions and to Dr. C. R. K. Blundell for information concerning the nature of sharpened steel edges, and also to Mr. D. H. Brown and Mr. D. M. Warman for making the instrument and to Mr. R. A. Boothby the photographer.

Mechanical trace reader

by E. W. NORTHOVER,* Mining Research Establishment, National Coal Board, Isleworth, Middlesex

MS. received 20th September 1960, in revised form 6th January 1961

Abstract

A simple mechanical trace reader is described that enables deflections recorded on paper or film to be read off, on a dial gauge, in any desired units when a movable cursor is set to the required points on the trace. Its use is illustrated for evaluating recorded temperatures, at various points and times, in a thermal model for the study of heat flow in the strata surrounding a mine airway. The trace reader gives a direct indication of the temperature difference ratio $(\theta_r - \theta_0)/(\theta_v - \theta_0)$, where θ_r is the temperature at the point in question and θ_0 and θ_v are fixed temperatures. It can be used in many other applications, provided that there is a linear relationship between the recorded quantity and trace deflection.

1. Introduction

THE evaluation of traces, on paper or film, produced by recording instruments can be a lengthy and tedious process, particularly when the record is unscaled or scaled in arbitrary units or when the indicated values must be corrected for off-set zero. The simple mechanical device described in this paper has been designed to aid trace reading in such circumstances. The instrument was originally designed for evaluating recorded thermocouple outputs from a small-scale heat conduction model (Hitchcock and Northover 1959), built to study heat flow in and from coal-mine strata, but it can be used in many other applications.

2. Description and operation of the instrument

Figure 1 shows a photograph of the trace reader. A transparent cursor A forms part of a carriage B which is moved by hand across the record. In so doing it alters the inclination of the lever C which is spring-loaded against two cylindrical pivots D and E, thus altering the reading of the dial micrometer F. In order to preserve the correct geometry of the system, the two pivots, and also the ball forming the tip of the dial micrometer plunger, have the same diameter.

It can be seen from Fig. 1 that the ratio of the movement of the cursor to the change in the reading of the micrometer can be altered over a wide range, using the main slide H. This ratio can be adjusted between the limits of 1.5 to 1 and 50 to 1.

Two further adjustments are provided on the instrument. The cursor is capable of separate adjustment relative to the lever operating pivot D, and also the body of the dial micrometer can be moved over a limited distance using the cross slide K, thus altering its reading. The instrument is arranged to accommodate recording paper having widths up to 6.0 in.,

and can be used to read traces having full-scale deflections between 0.3 and 6.0 in.

The principle of operation of the trace reader can best be illustrated if the method of setting-up the instrument for a typical record is described. For example, a record has been

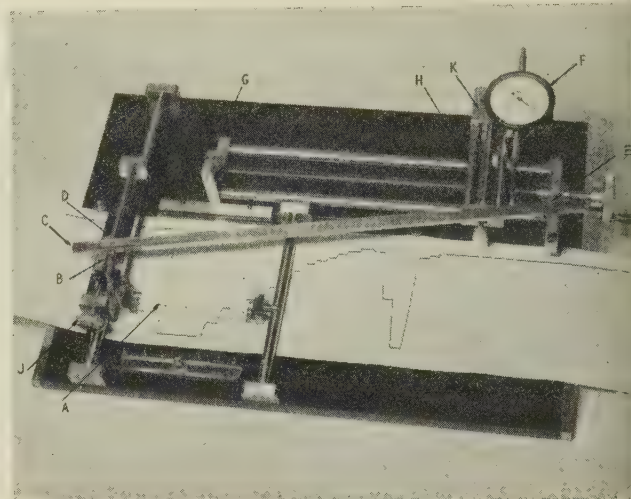


Fig. 1. Photograph of the trace reader.

obtained where the trace deflection corresponds to the output of a thermocouple, which is subjected to a varying temperature. The minimum deflection of the trace is equivalent to an e.m.f. of $10 \mu\text{v}$ and the maximum deflection to $715 \mu\text{v}$.

This record is inserted under the cursor of the trace reader with the highest level ($715 \mu\text{v}$) farthest away from the operator. The carriage is then moved until the lever reaches its stop. An initial adjustment is made to this stop, during manufacture, such that the plane edge of the lever is parallel to the direction of travel of the main slide H when it is in contact with the stop. By adjusting the screw J the cursor is moved independently of the lever until the cursor line coincides with the trace level representing $715 \mu\text{v}$. While still keeping the lever in contact with its stop, the body of the dial micrometer is moved with the cross slide K until it indicates 0.715 in.

The carriage is then moved, thus deflecting the lever, until the cursor line coincides with the level representing $10 \mu\text{v}$ and the dial micrometer is moved on its main slide H until it now indicates 0.010 in. It should be noted that the final setting of the micrometer to indicate 0.715 in. is unaffected by this movement of the micrometer on its main slide. Therefore after any intermediate level can be selected with the cursor and can be read off directly from the micrometer in microvolts.

It will be realized that this same record can be analysed in terms of temperature with the trace reader by setting the

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appropriate upper and lower values of temperature, either in °F or °C, into the micrometer in the manner described. The instrument can, of course, be used for the interpretation of recordings of any linear phenomena, e.g. electrical current, mechanical strain, etc.

Figure 2 shows, diagrammatically, the three settings of the cursor A when reading a trace typical of those obtained from

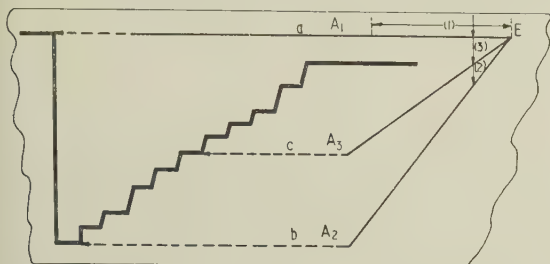


Fig. 2. Diagrammatic illustration using the trace reader.

the heat conduction model previously mentioned. The corresponding micrometer positions are shown by the arrows at (1), (2) and (3). While this trace could have been analysed in terms of temperature in the manner described above, for the special purposes of the model experiment the temperature ratio $(c - b)/(a - b)$ was required. Using the trace reader this is conveniently obtained, by setting up the instrument to read unity for a and zero for b . The cursor is then set to any intermediate level c and the ratio is given directly on the dial micrometer.

3. Tests and possible developments

The factors that can affect the accuracy of record interpretation using the trace reader, are the degree of mechanical precision attained in the manufacture of the instrument and also the variability, due to errors in setting the cursor precisely over the trace by various operators.

Simple tests were made to ensure that the general accuracy possible with the instrument was adequate for the purposes for which it was required. A 6 in. steel scale was clamped under the cursor and the dial micrometer was set at six

different positions on the main slide H, so that the six 1 in. steps could be read off over different ranges of units. These were 0-6, 0-12, 0-18, 0-24, 0-36 and 0-48. Four separate operators were employed to set up and read the instrument for each of these ranges, there being 168 settings in all. The consistency between the operators in reading the same level was always within plus or minus one division (0.001 in.) of the micrometer and the indication of the level was never in error by more than $\pm 0.5\%$ of the full-scale reading.

The analysis of traces having a centre zero was not considered when the instrument was designed. This is, however, accomplished by the addition of an identical dial micrometer mounted on an extension of the cross slide K and diametrically opposed to the original micrometer, but on a slightly higher plane. The plunger of this micrometer can be in contact with the edge of an additional lever mounted on the remote side of longer pivots at D and E, and positioned on the slide such that both micrometers indicate zero simultaneously. The instrument is then set up as described previously, the highest positive value and the centre zero being taken as calibrating levels. The trace can then be analysed directly with one dial indicating positive values and the other negative values of the trace.

Replacement of the dial micrometer by a three-digit counter would render the instrument even more convenient for routine use.

The makers of this instrument are W. H. Mayes and Sons (Windsor) Ltd., Vansittart Estate, Arthur Road, Windsor, Berkshire.

Acknowledgments

The instrument described in this paper was designed for use in the research programme of the Scientific Department of the National Coal Board and the paper is published by permission of the Director-General of Research. The author would like to thank his colleagues who made suggestions and assisted with the construction of the instrument.

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Tensile testing machine for whiskers

by H. B. M. WOLTERS and F. W. SCHAPINK, Koninklijke/Shell-Laboratorium, Amsterdam, Netherlands

MS. received 19th December 1960

Abstract

A screw-driven micro-tensile tester for whiskers is described. A synchronous motor moves one of the grips at a constant velocity, whereas the second grip is connected to a load cell in which a differential transformer is employed.

1. Introduction

IN recent years there has been a tendency in mechanical testing of materials to use machines of the 'hard' type, in which the necessary deflection for load measurements is kept to a minimum. As a consequence, the load measurement is difficult. In the case of whiskers and thin films, the small dimensions of the specimens cause additional difficulties, which have been discussed by Marsh (1959).

Several workers have constructed machines for testing whiskers in bending and in tension (Brenner 1957, Eisner 1955, Gyulai 1954, Pearson, Read and Feldmann 1957). On account of the uniform stress distribution, tension tests are to be preferred to bending tests, although the latter are easier experimentally. With the exception of the bending apparatus

of Pearson, Read and Feldmann (1957), all machines described so far were of the 'soft' type, not suitable for detecting drops in load. Brenner (1957) solved this difficulty by constructing a micrometer-operated brake in his tensile tester, which reduced the loading force immediately after the yield point of copper whiskers was reached. However, rapid load fluctuations during plastic flow may not be detected in this way.

It was therefore thought worth while to have a tensile tester for whiskers by which these fluctuations could be reliably detected. The authors accordingly constructed the apparatus described below, which is of the 'hard' type, operating at constant speed of deformation.

2. Description of the apparatus

The principal part of the apparatus is shown schematically in Fig. 1. The specimen is mounted by gluing it between two grips, A and B. A synchronous motor C rotates a spindle on which a nut with arm D moves the crosshead E at a constant speed (1 mm/h). Grip A forms an integral part of the moving core of a differential transformer F (Philips type).

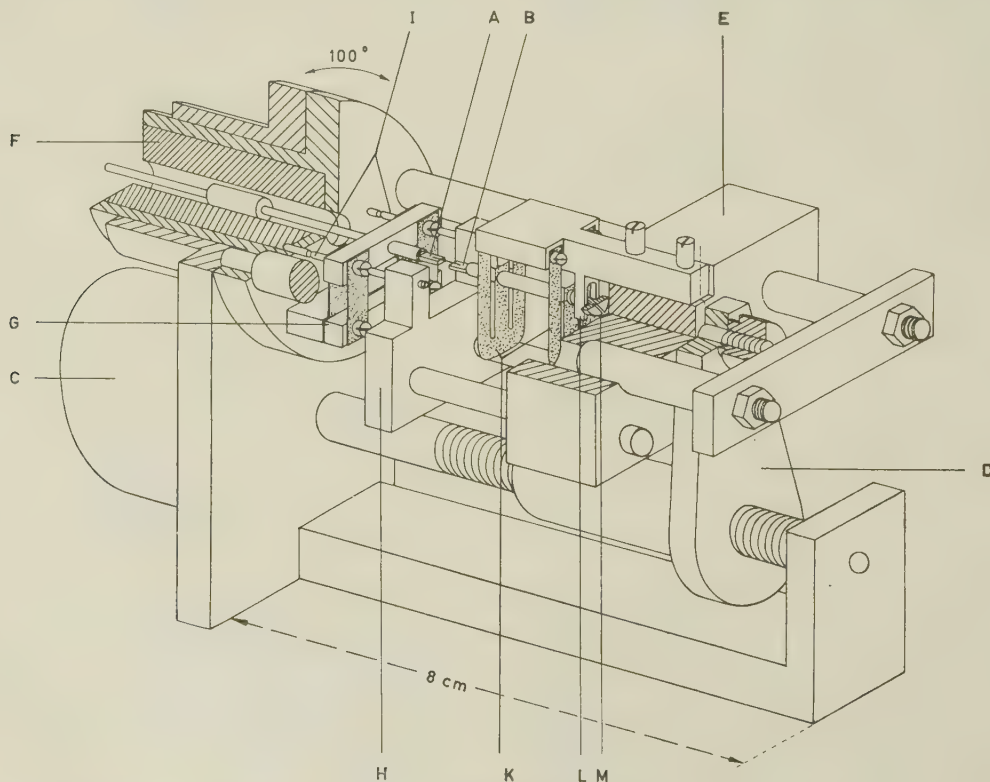


Fig. 1. Tensile testing machine.

R 9310) which is used as a load cell. The core is centred by means of four phosphor-bronze springs (thickness 0.15 mm) mounted rigidly at G. The output signal of the transformer is amplified and recorded as a function of time on a high-speed recorder (Honeywell-Brown Elektronik, type 153X16, $\frac{1}{4}$ s full-scale). The design of the tensile tester is such that the unit consisting of crosshead, guides, grips, whisker and load cell may be rotated through an angle of 90° . This allows one of the side faces of the whisker to be viewed with a microscope under optimum lighting conditions. The adhesive used is S-diphenylcarbazide; for its application the grips can be heated by means of two small coils. Two auxiliary devices were incorporated in the tester.

(i) Before each tensile experiment the speed of the machine is recorded in order to check the constancy of motion of the crosshead. This is necessary as the spindle-and-nut system may become dirty after some time, causing irregularities in motion. Before the specimen is mounted, the yoke H, forming part of crosshead E presses the spring system G against two stops I. After mounting the specimen and starting the motor, the crosshead together with the yoke H moves to the right, thereby unloading the spring system. In this way the motion of the crosshead is recorded (see Fig. 2,A), until the spring system is in its original position, as indicated by the breaking of an electric contact between H and G.

(ii) The thermal contraction of the specimen and grips,

caused by the cooling after mounting of the specimen, is taken up by the flexible mounting of grip B. Grip B is connected to the crosshead by means of a system comprising two E-shaped leaf springs K (thickness 0.03 mm) and stop L. As soon as the yoke H releases the spring system, the small force necessary to pull the mount until the adjusting screw M rests against stop L is measured by the recorder (Fig. 2,B). Now the tensile test proper starts, and the whisker is pulled at a constant speed of deformation.

The gauge length of the specimen can be varied by adjusting the position of the nut and arm on the spindle and is measured by means of a low-power measuring microscope. At the maximum sensitivity of the amplifier, a load of 1.7 g corresponds to full scale on the recorder. The influence of vibrations was reduced as much as possible by placing the machine on solid or foam rubber supports.

By virtue of its small size, the instrument may easily be placed in a vacuum or in an inert gas atmosphere, so as to avoid contamination of the sample during testing.

3. Performance

Figure 2 is a reproduction of a load-time curve recorded on the machine for a 9μ copper whisker (orientation [100]) grown from Cu_2I_2 by hydrogen reduction (Brenner 1956). After the yield point is reached, a Lüders band propagates through the crystal with a fluctuating load. Subsequently,

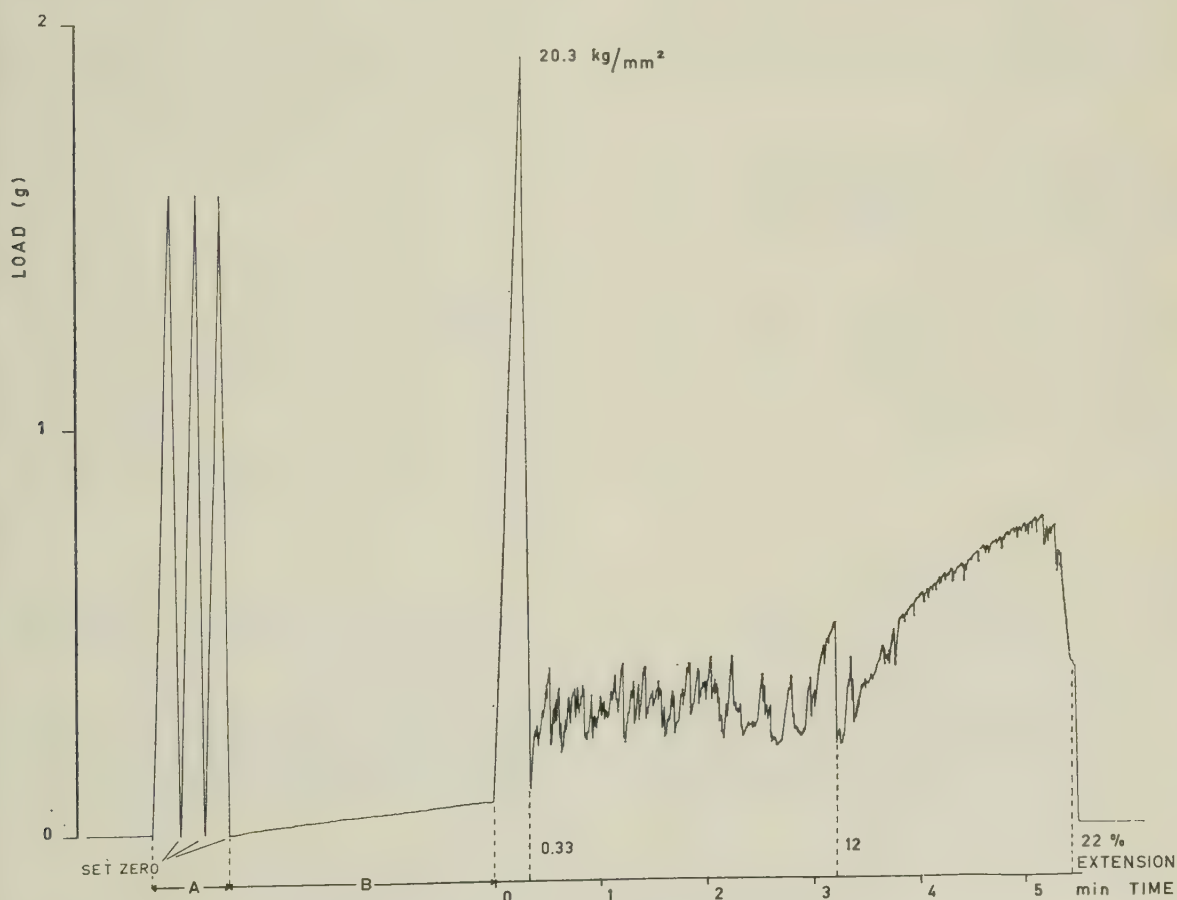


Fig. 2. Load-time curve of a [100] copper whisker.
A, motion of the crosshead; B, pull on the flexible mount.

work hardening sets in with gradually increasing load. It may be noticed that the drops in load are recorded with a minimum of smoothing off. The micro-tensile tester described in this paper is thus especially suitable for detecting yield points and plastic flow irregularities in whiskers.

Acknowledgments

The authors wish to thank Mr. A. W. Sleeswyk for a number of valuable suggestions, and Mr. A. W. Mul for his skilful building of the apparatus.

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Notes and Comments

Fourth International Rubber Technology Conference, 1962

The Institution of the Rubber Industry is holding its Fourth International Rubber Technology Conference at the Church House, Westminster, London, from May 22nd to 25th 1962.

The main sections of the Conference will be: Latex science and technology; General rubber technology—equipment, processing, compounding and evaluation; Rubber science—chemistry, physics, testing, analysis; Materials and products—rubbers, textiles and ingredients.

The papers will be available to Conference members as pre-prints and each author will be given 10–15 minutes to summarize, in order to leave ample time for discussion. A large number of papers will be presented by U.K. delegates and present indications are that delegates from eleven other countries will also present papers.

Further details regarding papers, authors and officials will be issued in due course by the Institution of the Rubber Industry.

2nd International Congress on Cybernetics

The International Association for Cybernetics has just issued the *Proceedings of the Second International Congress on Cybernetics*, held at Namur, Belgium, in September 1958.

This important scientific publication, which includes 80 of the papers read at the Congress, is available from the Secretariat of the 'Association Internationale de Cybernétique, A.S.B.L.', rue Basse-Marcelle 13, Namur, Belgium. Price 800 Belgian francs for members of the Association and 1200 Belgian francs for non-members.

Mining and Chemical Products Ltd.

Mining and Chemical Products Ltd. announce the publication of four technical booklets on the following subjects: Semiconductors; Thermoelectric materials; Bismuth telluride semiconductors; Galvanomagnetic effects and materials. Copies are available on request to Mining and Chemical Products Ltd., 86 Strand, London, W.C.2.

Soviet Physics—Doklady

The American Institute of Physics announce that the journal *Soviet Physics—Doklady*, now published every other month, will appear monthly, starting with the July 1961 issue.

The journal is a translation of the physics section of *Doklady Akademii Nauk SSSR—the Proceedings of the Academy of Sciences, USSR*. Editorial policy for this periodical emphasizes original research, breadth of coverage, brevity of contributions and speed of publication. Enquiries regarding the journal should be addressed to the American Institute of Physics, 335 East 45 Street, New York 17.

Post-Graduate Course in Welding Technology

The Institute of Welding announces the organization of a new one-year Post-Graduate Course in Welding Technology to be held at the College of Aeronautics, Cranfield, starting in the Autumn Term 1961.

The course is a compound of mechanical and civil engineering and metallurgy and is organized with the object of producing a specialist in welding science and technology.

Forms of application may be obtained from The Warden, The College of Aeronautics, Cranfield, Bletchley, Bucks.

former HT. The pulse in the secondary coil of HT triggers a univibrator UV₁ which applies a positive square pulse to the grid of V₂. During a predetermined period τ_1 the grid voltage is brought to zero with respect to the cathode of V₂, and V₂ becomes conducting. The voltage drop across R* is then approximately 100 v and acts as a bias for the quenching tube V₁. Consequently the voltage U_{V1} increases to a high value, and U_R correspondingly decreases to a low value and is held there during the time interval τ_1 ; in this way a quenching pulse is applied to the counter tube; e.g. with U_S = 4000 v and R = 3 M Ω a bias of 100 v causes a voltage drop at V₁ of approximately 2000 v; therefore the counter voltage drops from 3950 v to about 2000 v. With the potentiometer R* each value for the quenching pulse between zero and 2000 v is obtainable. No capacitor lies in the path from the plate of V₂ to the grid of V₁ or from the cathode of V₁ to the anode of the counter. Thus the voltage drop across the counter caused by a square pulse appearing at the plate of V₂ is independent of the counting rate; in particular, the counter voltage never exceeds the normal value whether the counting rate is low or high.

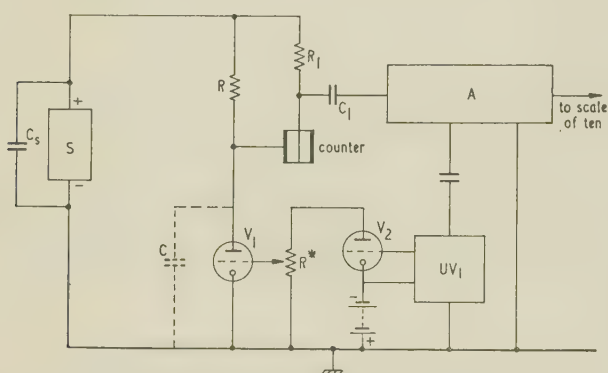


Fig. 2. Modified quenching circuit.

3. Details of the quenching circuit

To obtain the best action of the quenching circuit, some details must be considered. Between point (a) in Fig. 1 and the ground there exists a parasitic capacitance C, which, of course, should be as small as possible. At the moment of biasing V₁ with a square pulse at the plate of V₂ the counter voltage is determined by the charge of C; for a rapid drop of the counter voltage, the time constant RC must be small so that C loses its charge quickly. When, therefore, an a.c. power supply for the univibrator UV₁ and for the tubes (filament) and V₂ is used, the capacitance between the secondary and the primary of the power transformer must be kept very small. A low capacitance (about 10 pF) has been attained by a special construction of this transformer, part of which can be seen in Fig. 4.

Nevertheless, interference pulses from the mains appear at point (a) in respect to ground, and therefore (to a lesser degree) also at the input of the amplifier. Because of the high amplification factor of A—considering that a counting pulse of 0.3 mv can be recorded—two steps are taken here to prevent the recording system from responding to the noise. First, a filter system (F₁, F₂, see Fig. 3) is applied between the primary of T and the mains. The second measure will be discussed in the next section. (To avoid such difficulties the quenching circuit can be modified as shown in Fig. 4. In this modification for the supply of the voltages for UV₁ and V₂ an ordinary transformer can be used; furthermore the noise voltage cannot be so effective here because of the action of the capacitor C_S. Unfortunately, the cathode of the counter cannot be grounded; for this reason the circuit shown in Fig. 1 is preferred.)

The square pulse appearing at the cathode of V₁ should act on the counter with as little distortion as possible, i.e. the time constant R₁C₁ should be small. On the other hand, in order to obtain high sensitivity and freedom from interference the resistance of R₁ should be high. With R₁ = 2 M Ω and C₁ = 8 pF a tolerable compromise is obtained.

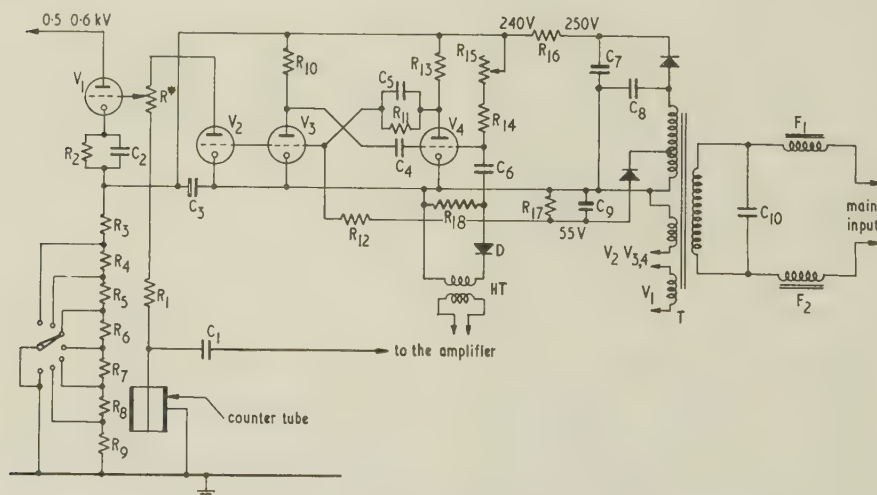


Fig. 3. Circuit diagram of the quenching circuit.

R₁ = 2 M Ω , 1 w
R₂ = 3 k Ω , $\frac{1}{2}$ w
R₃-R₉ = 600 k Ω , 2 w
R₁₀ = 15 k Ω , $\frac{1}{2}$ w
R₁₁ = 0.3 M Ω , $\frac{1}{2}$ w
R₁₂ = 80 k Ω , $\frac{1}{2}$ w
R₁₃ = 15 k Ω , 2 w
R₁₄ = 0.4 M Ω , $\frac{1}{2}$ w
R₁₅ = 5 M Ω
R₁₆ = 1 k Ω , $\frac{1}{2}$ w

R₁₇ = 12 k Ω , $\frac{1}{2}$ w
R₁₈, R* = 100 k Ω
C₁ = 8 pF, 10 kv tested
C₂ = 0.05 μ F
C₃, C₇ = 16 μ F
C₄ = 0.0015 μ F
C₅ = 100 pF
C₆ = 200 pF
C₈ = 0.03 μ F

C₉ = 10 μ F
C₁₀ = 0.5 μ F
D = crystal diode
HT = h.f. transformer
V₁ = RV275 (Telefunken)
V₂ = EC92 (Philips)
V₃, V₄ = ECC81 (Philips)

Figure 3 shows the complete diagram of the quenching circuit, except the standard type high voltage power supply. The well-known univibrator will not be discussed here; for details see Elmore and Sands (1949). The crystal diode D ensures a correct triggering of the univibrator by preventing positive pulses from arriving at the grid of V_4 . The RC network (R_2 , C_2) at the cathode of the quenching tube V_1 serves only to prevent grid current from flowing through R^* ; otherwise a handling of the potentiometer would produce enormous pulses large enough to be recorded.

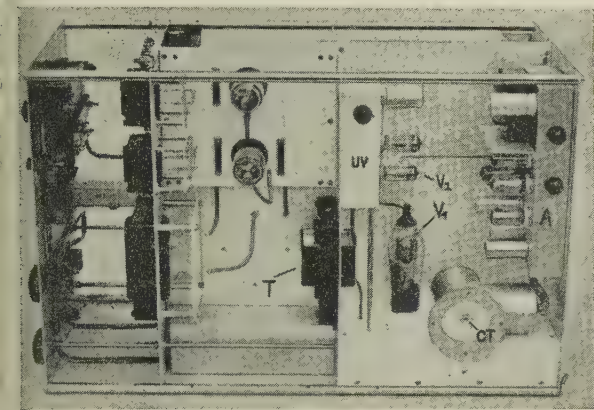


Fig. 4. The quenching circuit and the amplifier.

In Fig. 4 the transformer T , the lucite chassis UV for the univibrator and the valve V_2 , the quenching tube V_1 , the amplifier A and the shielded input (the socket CT for the connection of the counter tube) are seen; the shielding protects the anode resistance R_1 and the coupling capacitor C_1 .

4. The amplifier

The amplifier must be (i) highly sensitive to counter pulses, (ii) insensitive to noise, (iii) free from self-oscillation, and (iv) resistant to overloading.

The first requirement has been fulfilled by providing a sufficient number of stages, the second by suitable shaping of the frequency-response curve. The interfering frequencies from the mains lie mostly below 5 to 10 kc/s while the rise time of the counter pulses is of the order of some microseconds. Consequently the sensitivity of the amplifier has been kept low for the low frequencies, but high for the frequencies corresponding to the rise time of the counter pulses. Thus the gain of the amplifier is not constant over a wide range of frequencies; this is permissible in equipment to be used for the measurement of intensities but not of energies.

Immunity from self-oscillation, however, has been a serious problem. It is not sufficient to avoid interaction between the stages of the amplifier by good shielding and careful wiring. The rectangular quenching pulse lies not only across the counter tube, but also at the input of the amplifier. The square pulse will be differentiated by the small capacitor C_1 so that two pulses appear. The first pulse I^- is practically simultaneous with the counter discharge which provoked the square pulse, and has no further effect except to overload the stages of the amplifier, for the quenching pulse may have a magnitude of 2000 v. The second pulse I^+ corresponds to the voltage rise at the end of the quenching period; this pulse must be eliminated so that it cannot trigger the univibrator UV_1 a second time, or else the circuit would go into continuous oscillation.

In previous quenching circuits the pulse I^+ was suppressed because of its positive sign which differs from that of the counter pulse. However, this suppression (e.g. by means of a diode) is not complete so that even the counter pulses must not be amplified too strongly. In the quenching circuit discussed here the pulse I^+ is eliminated in a manner which does not impair the sensitivity of the amplifier for discharge pulses; the sensitivity is only limited by the noise level.

The first stages of the amplifier are shown in Fig. 5. Between the grid of V_5 and the ground an inductance L_1 of about 20 mH and a very low self-capacitance C' is inserted. Each pulse appearing at the input of the amplifier (a counter

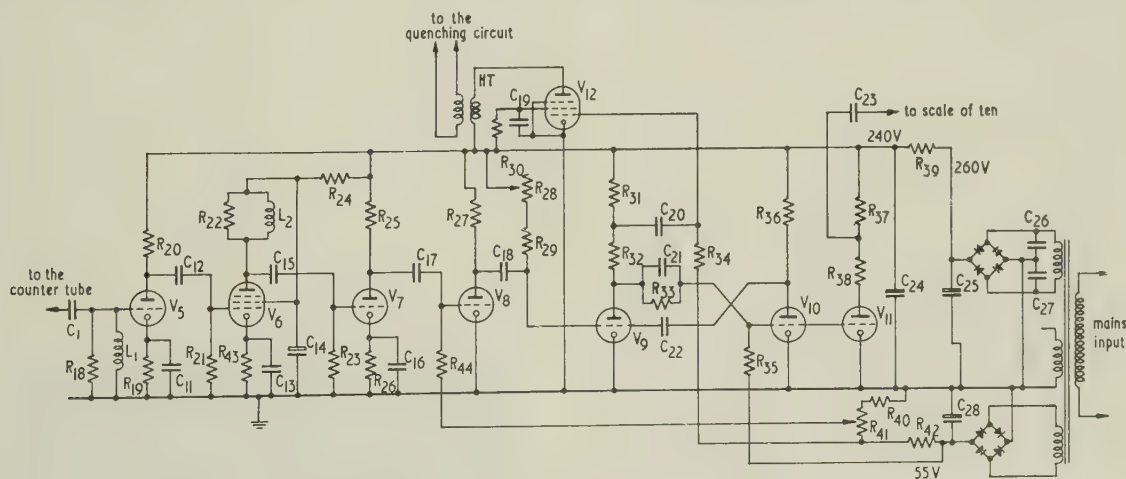


Fig. 5. Circuit diagram of the amplifier.

$R_{18} = 0.2 \text{ M}\Omega$, $\frac{1}{2} \text{ w}$
 $R_{19} = 500 \Omega$, $\frac{1}{2} \text{ w}$
 $R_{20}, R_{21}, R_{25} = 0.1 \text{ M}\Omega$, $\frac{1}{2} \text{ w}$
 $R_{22} = 20 \text{ k}\Omega$, $\frac{1}{2} \text{ w}$
 $R_{23} = 0.15 \text{ M}\Omega$, $\frac{1}{2} \text{ w}$
 $R_{24} = 7 \text{ k}\Omega$, 1 w
 $R_{26} = 600 \Omega$, $\frac{1}{2} \text{ w}$
 $R_{27} = 10 \text{ k}\Omega$, $\frac{1}{2} \text{ w}$
 $R_{28} = 5 \text{ M}\Omega$
 $R_{29} = 0.6 \text{ M}\Omega$, $\frac{1}{2} \text{ w}$
 $R_{30} = 50 \text{ k}\Omega$, $\frac{1}{2} \text{ w}$
 $R_{31} = 10 \text{ k}\Omega$, 1 w
 $R_{32} = 5 \text{ k}\Omega$, $\frac{1}{2} \text{ w}$

$R_{33} = 0.3 \text{ M}\Omega$, $\frac{1}{2} \text{ w}$
 $R_{34} = 0.2 \text{ M}\Omega$, $\frac{1}{2} \text{ w}$
 $R_{35} = 80 \text{ k}\Omega$, $\frac{1}{2} \text{ w}$
 $R_{36} = 15 \text{ k}\Omega$, $\frac{1}{2} \text{ w}$
 $R_{37} = 70 \text{ k}\Omega$, $\frac{1}{2} \text{ w}$
 $R_{38} = 15 \text{ k}\Omega$, $\frac{1}{2} \text{ w}$
 $R_{39} = 1 \text{ k}\Omega$, $\frac{1}{2} \text{ w}$
 $R_{40} = 7 \text{ k}\Omega$, $\frac{1}{2} \text{ w}$
 $R_{41} = 30 \text{ k}\Omega$
 $R_{42} = 20 \text{ k}\Omega$, $\frac{1}{2} \text{ w}$
 $R_{43} = 200 \Omega$, $\frac{1}{2} \text{ w}$
 $R_{44} = 0.3 \text{ M}\Omega$, $\frac{1}{2} \text{ w}$

$C_1 = 8 \text{ pF}$, 10 kv tested
 $C_{11} = 0.04 \mu\text{F}$
 $C_{12} = 0.005 \mu\text{F}$
 $C_{13} = 0.04 \mu\text{F}$
 $C_{14} = 4 \mu\text{F}$
 $C_{15} = 400 \text{ pF}$
 $C_{16} = 0.02 \mu\text{F}$
 $C_{17} = 0.005 \mu\text{F}$
 $C_{18} = 100 \text{ pF}$
 $C_{19} = 0.02 \mu\text{F}$
 $C_{20} = 200 \text{ pF}$
 $C_{21} = 100 \text{ pF}$
 $C_{22} = 0.002 \mu\text{F}$

$C_{23} = 700 \text{ pF}$
 $C_{24}, C_{25} = 16 \mu\text{F}$
 $C_{26}, C_{27} = 0.005 \mu\text{F}$
 $C_{28} = 10 \mu\text{F}$
 $L_1, L_2 = 20 \text{ mH}$

HT = h.f. transformer

$V_5, V_6 = \text{ECF80 (Philips)}$
 $V_7-V_{10} = \text{ECC81 (Philips)}$
 $V_{11} = \text{EC92 (Philips)}$
 $V_{12} = \text{EF40 (Philips)}$

pulse, a pulse I^+ or an interfering pulse from the mains) causes only a transient (Fig. 6) because the interval between the individual pulses is long compared with the natural period of the circuit L_1C' . The height of the amplitudes a_i depends on the amplitude of the incoming pulse. The transients are damped by R_{18} and by the diode constituted by the grid and the cathode of V_5 so that the amplitude is sufficiently reduced in a short time even when the oscillations were provoked by the high amplitude of the quenching pulse.

Though in this way overloading is not avoided, it will come to an end in the relative short time of 20 to 60 μs , depending on the amplitude of the quenching pulse. The period of the circuit L_1C' is of the order of 5 μs , and therefore the impedance will be about 200 $k\Omega$ for discharge pulses; however, for the noise frequencies the impedance decreases to a value of about 1 $k\Omega$ so that the interference pulses from the mains will be nearly shorted.

The coil L_2 is built just as L_1 ; the change in voltage at the plate circuit of V_6 is similar to that shown in Fig. 6. Thus

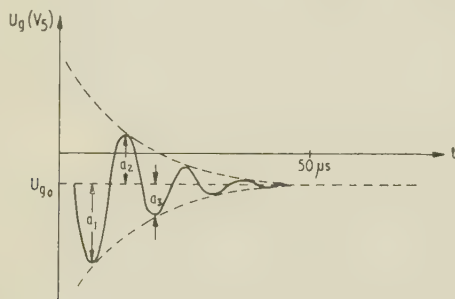


Fig. 6. Transient phenomenon at the grid circuit of V_5 .

each pulse applied to the input of the amplifier causes a highly amplified wave train to appear at the grid of V_8 . The tube V_8 is biased just beyond cut-off so that normally no plate current flows, and no voltage drop across R_{27} is observed. The positive amplitudes of the wave train will then produce a plate current, and some negative pulses appear across R_{27} or at the grid of the following univibrator UV_2 . The first of these pulses, provided it has a certain minimum size, transforms the univibrator quickly, at the moment t^* , into a quasi-stable state lasting a time interval τ_2 . At the moment $t^* + \tau_2$ the circuit moves back into the stable state, and a square wave appears at the plates of V_{10} and V_{11} (Fig. 7(e)). The negative pulses arriving at the grid of V_9 between t^* and $t^* + \tau_2$ do not appear at the plate circuit of V_9 and V_{11} (see Figs 7(b), 7(e)). If the condition $\tau_1 < \tau_2$ is fulfilled all unwanted pulses I^+ will be completely suppressed; the same applies to all counter pulses occurring between t^* and $t^* + \tau_2$, including spurious counts. Owing to this elimination of spurious counts, better plateaux are obtained even without quenching. The shortest interval τ_2 applicable in the apparatus described here is determined by the time needed for the decay of the transients, i.e. 60 μs .

The loss of counts can be calculated. If the dead time is τ_2 seconds and n' counts per second are recorded, the real number of events n is given by $n = n'/(1 - n'\tau_2)$ (Ruark and Brammer 1937); e.g. if 3000 counts per minute are recorded with $\tau_2 = 5 \times 10^{-4}$ s, then in reality 3080 events have occurred.

What happens when a pulse appears at the grid of V_9 immediately after the transfer of the univibrator to the stable state? Assume that the univibrator is triggered at

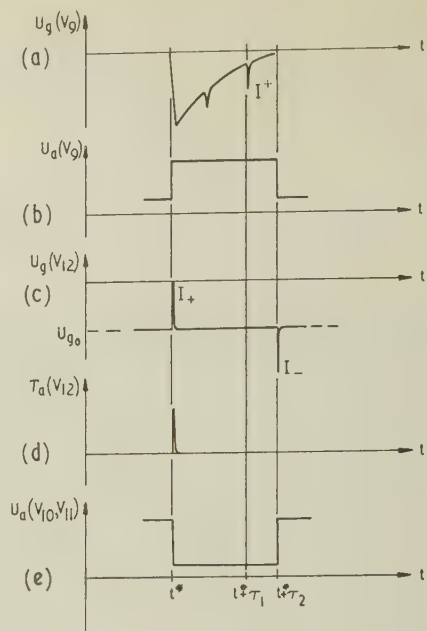


Fig. 7. Changes in voltage at the univibrator UV_2 .

the moment t^* , and that its quasi-stable state lasts from t^* to $t^* + \tau_2$ if no further trigger pulse appears. It is known (Elmore and Sands 1949) that the univibrator does not start again in the quasi-stable state for the time τ_2 if it is triggered a second time after $t^* + \tau_2$ but before $t^* + \tau_2 + \Delta$; Δ is called the recovery time. In this case the quasi-stable state will last a shorter interval than τ_2 , i.e. the dead time of the circuit is not constant, and the formula for calculating the counting error due to the dead time cannot be used. To avoid this Δ must be kept so small that the probability of an event between $t^* + \tau_2$ and $t^* + \tau_2 + \Delta$ can be neglected. A reduction of the recovery time Δ is achieved by a reduction of the resistance R_{36} of V_{10} . Moreover, a crystal diode can be inserted between the grid of V_9 and the ground (not shown in the diagram).

The square wave at the plate of V_9 is differentiated by means of an RC network (R_{32} , C_{20}), and the component of positive polarity (I_+ in Fig. 7(c)) increases the grid voltage of V_{11} . V_{12} which is normally strongly biased becomes conducting for a very short time, and the plate current flowing through the primary coil of the transformer HT produces a trigger pulse for the univibrator UV_1 . The component of negative

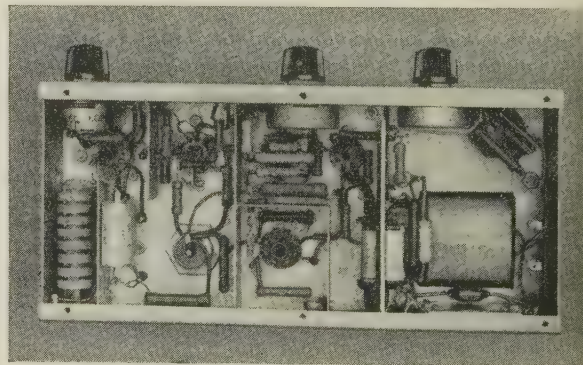


Fig. 8. The amplifier wiring.

larity is of no influence. The pulses for the recording system are obtained from the square wave appearing at the site of V_{11} .

Fig. 8 shows the wiring of the amplifier including the power supply. To avoid interactions between the stages of the amplifier, good shielding must be provided; at least L_1 must be shielded completely.

Acknowledgments

I wish to thank Professor E. Broda for suggesting this work and for discussions, and the Jane Coffin Childs Memorial Fund for Medical Research for financial assistance.

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Notes and Comments

A.E.I. Engineering. Associated Electrical Industries Ltd., 33 Grosvenor Place, London S.W.1.

We have received a copy of the first monthly number (January 1961) of *A.E.I. Engineering*, which is a technical journal produced by Associated Electrical Industries, 33 Grosvenor Place, London S.W.1, under the editorship of Dr. D. C. Milner. It covers the activities of the company as a whole, and replaces a number of house journals which have been discontinued. This issue, of 47 pages, contains articles entitled High voltage power transmission systems, 330 kv switchgear for Kariba, The precise measurement of small objects, Ships' radio emergency and distress equipment, prototype brushless a.c. generator, and Silicon diffused power transistors. There is also a short illustrated review of some of the company's products.

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An elastically hinged lever

by E. EISNER,* B.A. Ph.D., Safety in Mines Research Establishment, Ministry of Power, Portobello Street, Sheffield 1

MS. received 4th November 1960, in revised form 20th February 1961

A photographic quarter-plate was to be located in its plane against two stops bearing on one long edge and another bearing on a short edge. The positions of these stops were to be independently adjustable through 0.4 mm in directions in the plane of the plate and approximately normal to the glass edges against which the stops bore. The movements were to be approximately tenfold reductions of the movements of standard screw micrometers, and the reducing devices had to be very compact and robust, and also extremely rigid, especially against the reactions on the photographic plate. Further, the plate was to be left completely unobstructed on both sides. Lastly, each movement was, if possible, to be parallel to the axis of its operating micrometer, and the load on the micrometer was not to exceed 2 kg.

This note describes how the problem was solved by using three independent units in each of which a stop was moved by a second-order lever. This lever (L, Fig. 1) was elastically

hinged on a torsion-bar A_1 . Since the plate was to be unobstructed, the movement of the lever was communicated by a second torsion-bar A_2 to a frame C that carried stop P against which the photographic plate bore. The frame was carried on two parallel elastic strips B so that it was free to move only parallel to itself and nearly in a straight line. The lever was held against the spherical end of micrometer M by a tension-spring S so that the total movement of P (0.4 mm) was symmetrical about the position in which the torsion-bars and the leaf-springs were unstrained. Both the torsion-bars and the leaf-springs were effectively encastered by rigid clamping plates held in place by screws. The lever (Fig. 2) consisted of three parts, held together by two 10 B.A. screws so as to clamp the torsion-bars.

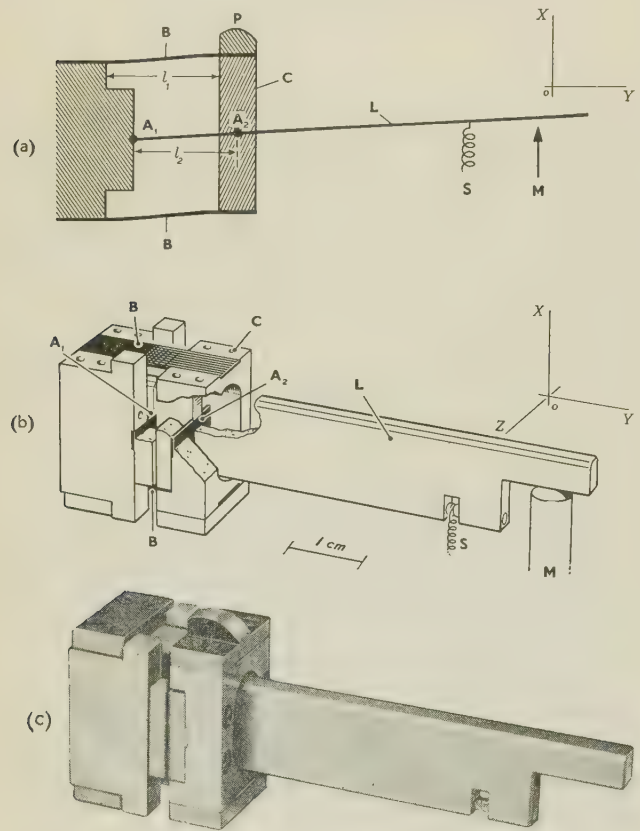


Fig. 1. The platform C is guided in parallel motion by springs B and is driven by the rigid lever L which is hinged on flat torsion-bars A_1 and A_2 . The movement of the screw-micrometer M is reduced tenfold at P.

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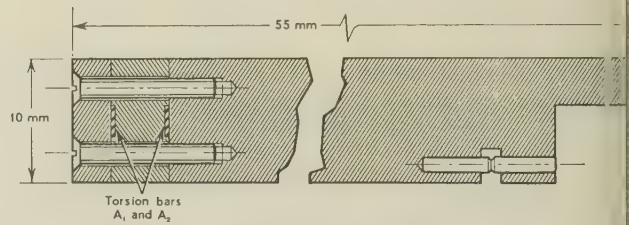


Fig. 2. Lever L showing the method of clamping the torsion-bars A.

Let us take orthogonal coordinates as shown in Fig. 1. The torsion-bar hinges A_1 and A_2 were strips of spring steel 0.2 mm thick and 2.4 mm wide set with the width parallel to oX ; they were therefore very stiff against the X and Z components of the reaction of the photographic plate on the lever. The elastic strips B (section 0.33 mm $\times$ 6.4 mm) provided the stiffness against the Y component of this reaction and added to that against the Z component.

Let us consider a rigid platform like C, supported by elastic strips of length l_1 parallel to oY , but otherwise free. If it is deflected by a force parallel to oX , then the components of the deflection in the X and Y directions are related by

$$y_1 = \frac{3}{5} \frac{x_1^2}{l_1} \left\{ 1 + \frac{12}{35} \frac{x_1^2}{l_1^2} + O\left(\frac{x_1^4}{l_1^4}\right) \right\}.$$

Similarly, if a rigid beam of length l_2 (corresponding to the part of the lever between the torsion-bars, see Fig. 1) is hinged at one end and the other end is deflected, then

$$y_2 = \frac{1}{2} \frac{x_2^2}{l_2} \left\{ 1 + \frac{1}{4} \frac{x_2^2}{l_2^2} + O\left(\frac{x_2^4}{l_2^4}\right) \right\}.$$

Therefore, if

$$x_1 = x_2 = x \text{ and } l_1/l_2 = 6/5,$$

then

$$y_1 - y_2 = -\frac{9}{875} \frac{x^4}{l_1^3} + O\left(\frac{x^6}{l_1^5}\right).$$

Thus, by making the leaf-springs B 20% longer than the distance between the torsion-bars, the maximum relative movement (as calculated from Eqn (4)) that had to be accommodated by bending the torsion-bars or stretching and tightening of the strips B was reduced to 1 Å. Such a small movement could be accommodated with negligible strain. (Actually the effect of neglecting the finite thickness of the beam and the effects of inaccuracies in construction are greater than this, but these effects, too, are completely negligible.)

The dimensions of the elastic components were determined as follows. The distance (46 mm) of the point of application of the micrometer from the torsion-bar A_1 was determined from the amount of room available, viz. the longer dimension of a quarter-plate. As tenfold reduction was required, this determined the distance between the torsion-bars (4.6 mm). The dimensions (free length, thickness and width) of the torsion-bars were determined by considering the couple which determined the load on the micrometer and the strain for the maximum required deflection (± 0.2 mm at P), and then compromising between the dimensions giving maximum strength and maximum rigidity against the load at P. The length of the parallel leaf-springs was determined from Eqn (3). Their width (6.4 mm) was determined by convenience

(stiffness $\propto$ width); the thickness (stiffness $\propto$ thickness³) was determined by the need to avoid a large additional load on the micrometer and too high a strain in the leaf-springs. This thickness (0.33 mm) turned out to give ample rigidity against the couples produced by the torsion-bars. Some of the (calculated) mechanical characteristics of the device are as follows:

Stiffness against loads at P, with the free end of the lever rigidly supported	3 kg/micron.
Maximum permissible load at P, under the same conditions	16 kg.

For a deflection of 0.2 mm at P:

Strain in the torsion-bars	0.45%
Strain in the leaf-springs	0.07%
Load on the micrometer in addition to that produced by the retaining-spring S	0.7 kg.

Acknowledgment

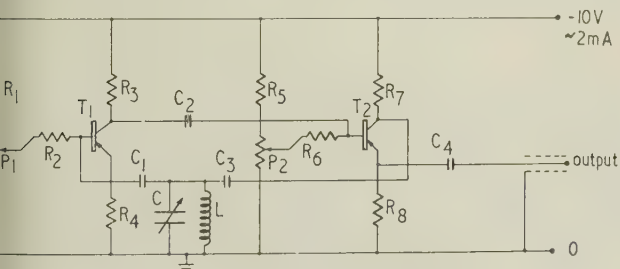
The author gratefully acknowledges helpful comments by a referee. The drawings are reproduced by permission of the Director Controller, Her Majesty's Stationery Office. The author wishes to thank the Safety in Mines Research Establishment for permission to publish.

Two-transistor oscillator for displacement measurements

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MS. received 25th January 1961

It is a well-known technique to use as transducer a small capacitor, whose changes in capacitance are related to small longitudinal movements. These variations may be measured by making this capacitor part of the LC circuit of an oscillator (see Figure) and by following the corresponding changes in frequency.



Circuit diagram of the oscillator.

$R_1 = 47 \text{ k}\Omega$
 $R_2 = 4.7 \text{ k}\Omega$
 $R_3 = 5 \text{ k}\Omega$
 $R_4 = 100 \Omega$
 $R_5 = 50 \text{ k}\Omega$
 $R_6 = \text{transducer capacitance}$
 $R_7 = 2 \text{ pF}$

$C_2 = 10 \text{ pF}$
 $C_4 = 500 \text{ pF}$
 $T_1, T_2 = \text{RCA 2N 247}$
 $L = 57 \text{ turns of } 0.03 \text{ mm diameter wire, close-wound on } 10 \text{ mm diameter quartz tube}$

stability. Of the many circuits possible the so-called 'Franklin' oscillator (Thomas 1951) is attractive because it leads to the possibility of a very small coupling between the LC circuit and the feedback network. The use of transistors, with a very small power consumption, makes it practicable to run the oscillator on a telephone dry-cell battery for more than a year without interruption. If the system is protected against fast temperature variations, first by embedding the two transistors in a brass block and secondly by protecting the oscillator and the battery with a thick layer of expanded polystyrene, a fairly good stationary state is attained after one or two days.

Under these conditions, for a frequency of 10 Mc/s the daily drift of the oscillator alone may be as small as a few cycles per second. In the particular application where this device was used (Sproull 1960) the drift with the transducer connected rose to 10 c/s per minute. This corresponded to a linear displacement of 0.3 Å.

This work was part of a research project sponsored by the Union Carbide Corporation, New York.

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Evidently the sensitivity of such a system is limited by the stability of the oscillator, and especially by its short-term

Device for protecting recording pens from interference from surgical diathermy

by W. W. MAPLESON, B.Sc., Ph.D., A.Inst.P., Anaesthetics Department, Welsh National School of Medicine, Cardiff

MS. received 15th February 1961

Surgical diathermy apparatus generates up to 100 w of radio-frequency energy which is usually modulated at mains frequency. During a surgical operation the current is applied to the patient by a needle electrode in order to cut tissue or to seal off cut blood vessels by coagulation. If electric potentials (electroencephalograms, electrocardiograms, etc.) are being recorded by a pen oscillograph the interference caused by the 50 c/s modulation of the diathermy is so large that the recording pens are liable to be broken, unless they are switched off almost immediately the interference starts. There are a variety of ways in which this might be done automatically. The present method has the advantage that it requires little or no modification of the recording equipment and no modification of, or connection to, the diathermy apparatus.

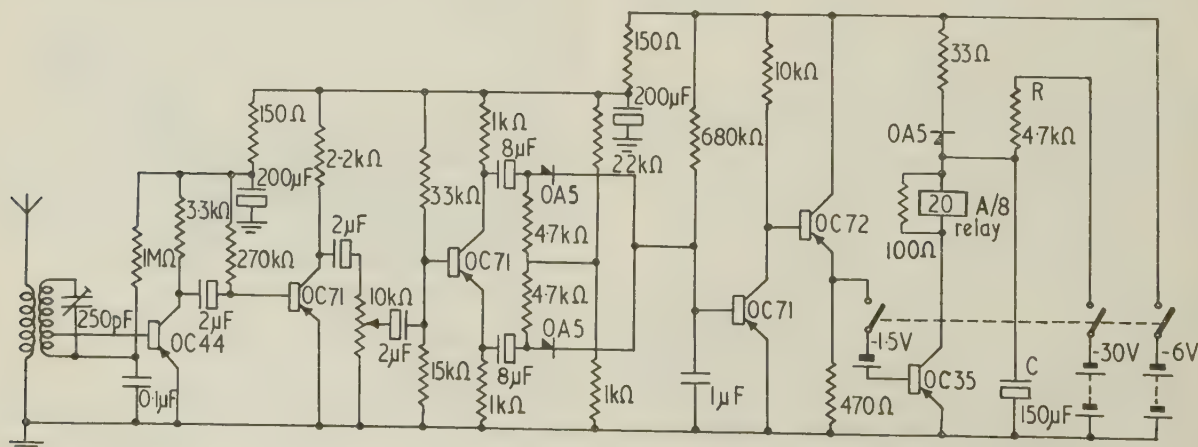
The principle of the method is to pick up the radio frequency radiation from the diathermy apparatus, amplify it and rectify it, and apply the output to a relay which switches the outputs of the recorder amplifiers away from the recording pens on to dummy loads. The circuit (see figure) is fully transistorized and battery operated. A single tuned circuit gives enough selectivity—unless, perhaps, the device were operated close to a radio transmitter. The first transistor operates as an r.f. amplifier and detector, the second as an a.f. amplifier, and the third as a phase splitter. A full-wave rectifier follows, so that the system responds to the first half-cycle of 50 c/s interference no matter whether it be positive- or negative-going. Three stages of d.c. amplification provide sufficient power to operate the relay. This is a type 3000 relay which will operate on 6 v and hold on 2 v, but a very rapid operate time has been achieved by means of C, R and the 30 v battery: when the diathermy is switched on the last transistor, the OC 35, becomes conducting and C discharges through it and the relay to produce an operate time of less than 6 ms. The relay is then held by a steady drain of about 100 ma from the 6 v battery (together with only 6 ma from the 30 v battery) for so long as the interference lasts. When the diathermy is switched off the OC 35 becomes non-conducting, the relay breaks and

C recharges within about 2 s ready for the next burst of interference. Some care is needed in the decoupling of the early stages of the amplifier, otherwise the making or breaking of the relay is liable to set the system into oscillation at a few cycles per second.

The present relay has eight change-over contacts so that it can protect up to four pens. The operate time of 6 ms allows the pens to be fully deflected once, before they are switched off. The operate time could be reduced to about 1.5 ms by replacing the type 3000 relay with eight high-speed relays, but when just two high-speed relays were tried for protecting one pen it was still fully deflected before being switched off. Presumably the interference is so great that it appears in the pen coils as a square wave with a very short rise time. However, before the device was in use, pens broke only if they were subjected to the interference for some seconds continuously, so that the device can be expected to give at least a greatly prolonged life to the pens. Since the device was completed there have been only a few occasions for its use so that it is not possible to say more than that some pens have survived about 100 operations of the device without any damage.

In its present form, with Belling-Lee 7-pin plugs and sockets, the device is designed primarily for use with Siemens Ediswan electrophysiological recording equipment. The output of the Ediswan amplifiers, which is normally plugged into the recorder, is instead plugged into the device which in turn, is connected to the recorder. The amplifier outputs are then normally fed through the device to the recorder but when diathermy interference occurs they are switched over to dummy loads within the device. For use with other recorders it would be necessary to bring the amplifier outputs out to a socket and the pen coil connections to a plug which would then be connected via the device.

I wish to thank Mr. A. Crookes, Chief Technician to the Physics Department, Cardiff Royal Infirmary, for suggesting this approach, and Mr. E. K. Hillard, Senior Technician in the Anaesthetics Department, for his assistance in constructing the device.



An effective splash trap for a manometer

by F. S. MAGUIRE and A. G. THOMAS, Australian Defence Scientific Service, Defence Standards Laboratories, Department of Supply, Maribyrnong, Victoria, Australia

MS. received 13th February 1961

When liquid-filled manometers are used to measure small pressure differences it is not uncommon for the manometric liquid to be sucked or blown over into the apparatus. The normal simple types of liquid traps are not completely effective and some carry-over usually results from splashing.

The trap described has high collection efficiency and drains rapidly, leaving the manometer ready for use with a minimum

of zero adjustment. It consists of a squat cylindrical glass chamber surmounted by a spherical bulb. A flat circular impaction plate is attached to the bottom of the cylindrical section by three short legs; the bulb is also fitted with an impaction plate having the form of a segment of a spherical shell which is attached similarly at a position just before the mid-section. The general arrangement is shown in the diagram.

The volume of the cylindrical section and of the spherical bulb should each be about three times that of the liquid contained in the system, and the diameter of the throat connecting the two vessels two and a half times the internal diameter of the manometer tube. The flat impaction plate should have a minimum diameter of at least three times that of the manometer tubing and be mounted 5 mm above the point of entry of this tube. The upper impaction plate should have a radius of curvature approximately equal to that of the bulb and for convenience in assembly should be mounted with its lower edge about 1 cm below the mid-section. The clearance between the edge of the plate and the wall of the bulb should be 5 mm. The dimensions given here have been found to be satisfactory for bulbs of volumes ranging from 50 ml. to 500 ml. Some minor modifications may be desirable outside this range.

The trap has proved effective for water, oil and mercury and should be satisfactory for any manometric fluid. The lower cylindrical chamber serves as a reservoir when the manometer is being used as a constant zero instrument. The trap still functions effectively when the impaction plate is covered with liquid.

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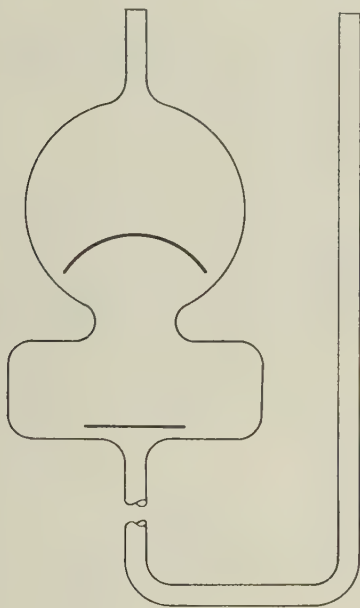


Diagram of splash trap.

Electroforming as a method of obtaining O-ring grooves

by S. R. RAJAGOPALAN, B.Sc., and R. RADHAKRISHNAN, B.E., Central Electrochemical Research Institute, Karaikudi 3, India

MS. received 28th February 1961

The purpose of this note is to describe an electroforming method for obtaining O-ring grooves, as used by us in the course of construction of a Finch-type electron diffraction camera. This equipment has a rectangular opening in the main body (the 'camera block') for the insertion of the photographic plate holder. A vacuum-tight seal between the camera block and plate holder can be obtained either by lapping the mating surfaces or by using an O-ring seal. The non-availability of lapping facilities necessitated the use of an O-ring seal. The O-ring dovetail groove, however, had to follow a shape defined by two parallel lines ($7\frac{1}{4}$ in. long) joining two semi-circles (radius 1 in.). The machining of such a groove was precluded because of the considerable difficulty involved.

As an alternative, a brass plate (4 in. $\times$ 7 in. $\times$ $\frac{1}{4}$ in. thick) was machined plane, and a Perspex replica of the dovetail

groove was wax-jointed to the brass plate in the position where the groove was required. After appropriate cleaning, the brass was plated with copper from an electroforming bath ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ — 200 g/l. and H_2SO_4 — 50 g/l.) at 30°C , using a current density of 25 A/ft^2 . The copper anode was covered with PVC cloth and the electrolyte was agitated with a stirrer. Continuous plating for fifteen days gave the required $\frac{1}{4}$ in. thickness. The surface was reduced to give the correct groove depth and the replica removed by heating. After a rectangular opening had been cut in the brass plate it was soldered on to the camera block. Observation of the plate section in a microscope revealed good adhesion.

We are grateful to Dr. A. K. N. Reddy for his encouragement and help, and to Professor K. S. G. Doss for his interest in this work.

Simple means of computing two-dimensional steady-state heat flow in composite systems

by D. W. STOPS, Ph.D., A.R.C.S., A.M.I.E.E., A.Inst.P., Bell's Asbestos and Engineering Ltd., Slough, Bucks.

MS. received 1st February 1961

The uses of electrolytic tanks, resistance networks and conducting paper are well-known for the solution by electrical analogues of potential flow problems involving complex geometries (Higgins 1956). In the case of the electrolytic tank, the thermal conductivities of various media in one complexity can be simulated by using electrolytes of different and appropriate conductivities, which must be separated physically by membranes with discrete electrical contacts to ensure continuity of current. Alternatively, a cellular material with interconnecting cells can be saturated with electrolyte and compressed differentially to present the appropriate volumes of liquid available for conduction (Reiniger 1956-57). Resistance networks can be graded for mesh size and resistances per square to provide any degree of accuracy required in the simulation, but this, like the electrolytic tank, involves considerable preparation. Conducting paper in conjunction with silver dispersion for contacts and the outlining of isopotential boundaries, can provide a quick, inexpensive yet accurate analogue for even complex physical systems, and for most purposes requires only modest associated measuring equipment.

The standard conducting paper (Teledeltos*) has resistance values of 500 ohms per square and upwards, with a local variation of resistance of less than 2%. This resistance can be increased by punching holes in the paper, and if this is done in a regular pattern, then the resistance will be substantially the same, irrespective of direction of current flow. Fig. 1 shows how the resistance per square increases with the

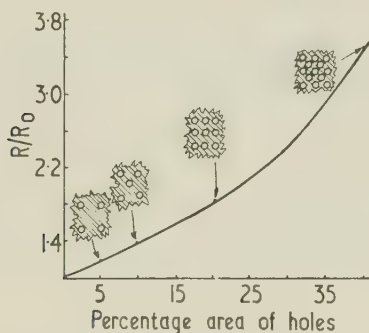


Fig. 1. Increase of resistance per square with area of punched holes.

area punched out in the manner illustrated. It is seen that for small ratios of holes to paper area, the resistance increases linearly with this ratio, but at higher values the curve becomes progressively steeper. However, an increase of a factor of four is easily achieved and, if a higher resistance ratio is required, holes which present a more zigzag path to the current flow can be cut. It is convenient to mount the paper on to a firm backing paper if a large percentage of any area is to be cut away, and at all times the pattern produced must be as uniform as possible when viewed from any aspect. The resistance of the paper cannot be reduced so easily; the

process of spotting the paper with silver paint is both tedious and of little effect until a very large ratio of the area covered. A reduction in resistance of a particular area is best achieved by setting parallel a number of plies of paper punched or otherwise, to suit the circumstances. The parallel pieces of paper must be electrically connected at discrete points; this can be done by spotting with silver cement (type FSP 49, by Johnson, Matthey and Co. Ltd). It conveniently happens that the conductivities of commercial insulants do not cover a wide range of values, so that many practical systems can be closely approximated to in the analogue by either punching the paper in appropriate places and/or laying other single pieces of paper in contact (face to face) with the base paper.

To illustrate the technique the following example is given. A piece of Teledeltos paper with straight and parallel silver bands on it, at a spacing of 6.4 in., conducts 42 mA when 25 v a.c. applied, for a path width of 6.8 in. That same paper with a conducting strip added to represent a projecting metallic girder, simulated here by paralleling an area of punched paper with the base paper, Fig. 2(b), increases its

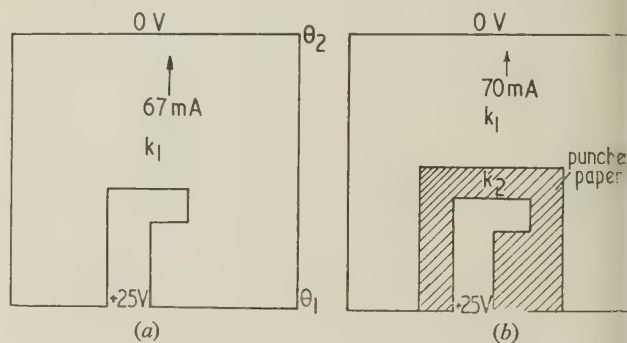


Fig. 2. Electrical analogue patterns.

current to 70 mA with the same voltage applied. The respective electrical resistances are in the ratio 1.0 : 0.62 : 0.62 and it is known that, for a similarly shaped thermal system with no heat flow across its bordering edges, the thermal resistances would have similar ratios, provided

$$k_2 = k_1 + k_1/3.25 \approx 1.3k_1.$$

This would correspond to the physical situation where k_1 is appropriate to expanded polystyrene with a thermal conductivity of 0.22 Btu/ft²h (deg F/in.) and k_2 is appropriate to foamed polyurethane with a value of 0.29 Btu/ft²h (deg F/in.).

The punching of holes, or application of discrete shorting elements, introduces small discrepancies in the similarity of the potential distribution between the actual system and the model. These perturbing effects can be reduced to any level by scaling down the patterns where desired.

The punching technique also provides an iterative means of allowing for the changes in conductivities with temperature. Consider the system shown by Fig. 2(a) and suppose the

* Standard Telephones and Cables Ltd.

$= 200^{\circ}\text{C}$ with $\theta_2 = 0^{\circ}\text{C}$. Then, initially, plots of isopotentials are made with a simple probe. Thus the areas which correspond to those embraced by the 200, 150, 100, and 0°C isothermals are drawn on the paper. If $k = k_0(1 + \alpha\theta)$ then values of k for mean temperature values for each region can be calculated and their resistance ratios found. If in this case $\alpha = 0.04\text{ deg}^{-1}$, then values of k are $1.7k_0$, $1.5k_0$, $1.3k_0$, $1.13k_0$, with resistance ratios of 1.13 , 1.30 , 1.50 respectively. Holes are then punched in the three lower potential zones to give corresponding resistance values. The percentage areas of holes are deter-

mined from the calibrating graph, Fig. 1. New plots of equipotentials give a closer approximation to the actual system, and the new value of total resistance gives a better estimate of the total heat flow. This process can obviously be carried out with a fine distribution of holes and as often as the problem warrants. Usually one such approximation is sufficient for all practical purposes.

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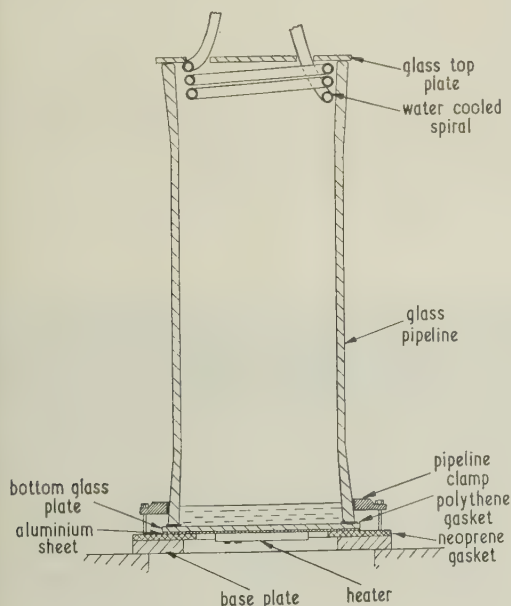
A simple trichlorethylene degreasing plant

by P. E. SECKER, B.Sc.(Eng.), Ph.D., Electrical Engineering Department, Queen Mary College, University of London

MS. received 3rd March 1961

When assembling parts of a high vacuum equipment, or preparing metal surfaces for specialized treatment, there is often a need for an efficient vapour degreasing plant. While trichlorethylene vapour degreasers are not uncommon on the factory floor, they are usually regarded as too large, expensive and messy for laboratory use. In this department, a compact degreaser has been developed, using readily obtainable proprietary components, which is not subject to these usual limitations.

As it was necessary to carry out degreasing of metal specimens without the possibility of depositing any contaminant on the treated surfaces, the vapour-liquid container of the degreaser was constructed entirely of glass (see Figure).



This eliminated the possibility of metal parts corroding, and enabled a close visual check to be kept on the cleanliness of the degreasant.

The body of the plant consisted of a PS6.18 section of Q.V.F. glass pipeline (Q.V.F. Ltd., Stoke-on-Trent), on top of which a glass plate rested, to prevent vapour loss to the laboratory. Vapour loss was further checked by fitting a water-cooled spiral just below the top plate, as shown. The base plate was an aluminium annulus, $\frac{1}{2}$ in. thick, of outside diameter 11 in. and inside 6 in. attached to a small Dexion frame, and thermally insulated from the rest of the degreaser by an $\frac{1}{8}$ in. thick neoprene gasket (Q.V.F. part CGN6). The bottom end of the glass column was sealed by an 8 in. diameter glass plate, $\frac{1}{8}$ in. thick, the join between the two parts being rendered leakproof by fitting a gasket cut from a sheet of 0.007 in. polythene. The bottom glass plate rested on a sheet of 18 gauge aluminium, 8 in. in diameter, which served both as a device for ensuring uniform heating of the trichlorethylene liquid, and as a support for the heater. The latter, a 350 w unit intended for the boiler of a diffusion pump (Edwards High Vacuum Ltd.), was fixed to the aluminium sheet using hot-setting Araldite type 1 (Ciba (A.R.L.) Ltd.). The glass column, heater assembly, glass sealing plate and base plate were held firmly together, using a standard Q.V.F. pipeline clamp (part CF6), attached to the base plate by studs fitted in the latter.

In practice it was found that the degreaser initially required about an hour to reach optimum operating temperature, but thereafter degreasing was complete in only a few minutes. No obnoxious fumes escaped from the plant, and the polythene gasket remained leakproof for several months despite the fact that strips of polythene dropped into the trichlorethylene when hot appeared to dissolve. The neoprene gasket, insulating the heated section from the base plate was similarly found to be serviceable after several months.

Articles for degreasing were suspended by plastic cord from the top cold water spiral, and the actual degreasing process was observed to occur exactly as in the normal industrial-type plant.

The author wishes to thank Dr. T. J. Lewis for helpful suggestions made during the construction of this equipment, and to acknowledge the award of a Research Fellowship by the Department of Scientific and Industrial Research.

Pneumatically driven shutter for high-speed cameras

by J. C. MUIRHEAD, B.Sc., and F. L. MCCALLUM, Physics and Meteorology Section, Suffield Experimental Station, Ralston, Alberta, Canada

MS. received 8th February 1961

High-speed streak and framing cameras of a sufficiently high recording rate to be useful in conventional shock tube studies are generally limited to a total writing time of about 10 ms. Thus, accurate shuttering is a problem. Mechanical shutters, consisting of an aperture in a falling plate, have been used

be achieved consistently in 500–600 μ s, using pressures 10 lb/in². Thus, on a camera writing for 10 ms, approximately $\frac{1}{10}$ of the film is exposed during opening and closing of the shutter, leaving 9 ms available for recording of the event. (The time needed for opening and closing would,

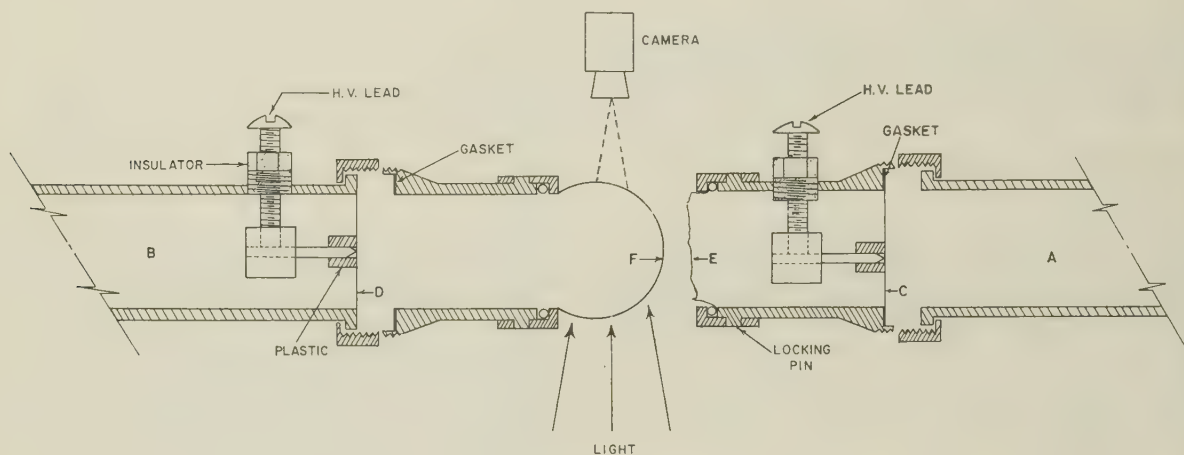


Fig. 1. Diagram of shutter.

A, compression chamber; B, evacuated chamber; C, D, shock tube diaphragms (0.001 in. cellophane); E, F, shutter diaphragms.

(Glass 1951). However, these generally require that the firing of the shock tube be triggered by the shutter. Devices for blocking the light beam at the end of the required exposure time have been constructed (Wurster 1957, Edgerton and Strabala 1956). These do not in themselves give control over the beginning of the exposure. A shutter for opening and closing a 20 micron slit in 5 μ s has also been described (Camm 1960).

This note describes a shuttering system which may be triggered by the event to be photographed, whose opening and closing are controlled electronically, and which has an aperture of up to 1½ inches.

A schematic diagram of the system is given in Fig. 1. Initially, light is prevented from reaching the camera by shutter diaphragm F. This diaphragm, and diaphragm E, are constructed of 0.0005 in. Mylar film with an opaque coating. Shock tube diaphragm D is then punctured electrically (McCallum and Muirhead 1960) by the discharge of a 0.1 μ F condenser at 7000 v. An expansion wave leaves the evacuated chamber B, pulling back shutter diaphragm F. After the required exposure time has passed, shock tube diaphragm C is punctured electrically and a compression wave leaves chamber A, forcing shutter diaphragm E outwards so that it blocks the light beam.

The speed at which the shutter operated was checked with a high-speed camera. Using a 1.5 in. diameter shutter, it was found that shutter diaphragm movement of 1.5 in. could

course, be less where the required movement of the shutter is less than 1.5 in.)

The principal problem involved in operation of the shutter is in preventing the high voltage discharge which punctures diaphragm D from triggering the discharge through diaphragm C. This can be avoided, however, through careful shielding and isolation of the circuits.

A photograph of the shutter assembly is given in Fig. 2.

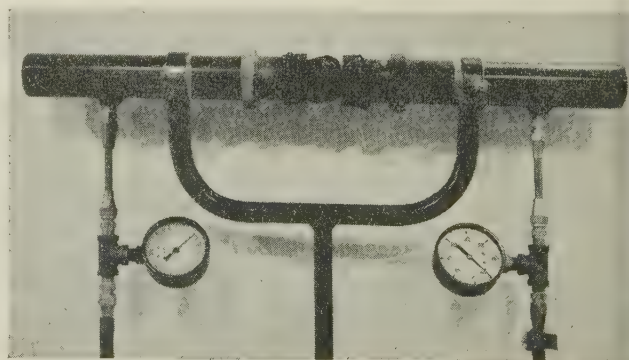


Fig. 2. Photograph of shutter assembly (electrical leads not shown).

This work was carried out under Defence Research Board project D89-16-01-09. Permission of the Defence Research Board to publish this note is gratefully acknowledged.

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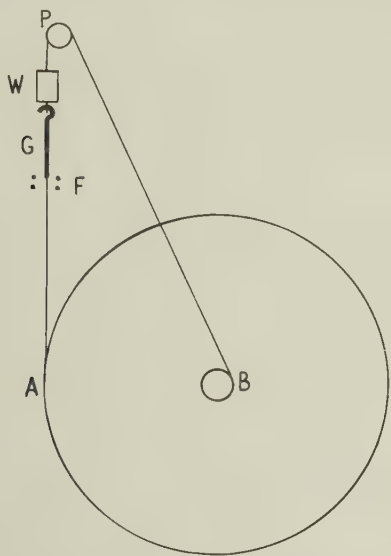
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A simple method of drawing glass fibres

by I. CHAVET, M.Sc., and B. DAVIDOF, Ministry of Defence, Scientific Department, Tel-Aviv, Israel

MS. received 12th December 1960, in revised form 20th February 1961

Because of the growing importance of fibre optics, a description of a simple method for drawing fibres from glass rods may be found useful. The principle of the method is illustrated in the Figure. The two concentric drums A and B are rigidly connected, but all free to revolve on their common



Schematic diagram of the assembly.

A, large drum; B, small drum; P, idle pulley; W, weight; G, glass rod; F, furnace.

axis. A flexible but inextensible wire, partly wound on B, hangs on the idle pulley P and is anchored to a weight W. This in turn holds the glass rod G which is drawn into the furnace F, and the formed fibre winds itself on the drum A. Because of the difference in the diameters of A and B, the system cannot move unless the glass rod G is stretched by a ratio equal to the ratio r of the diameters of the drums A and B. This is made possible by the furnace F. The ratio of the diameter of the glass rod and the fibre formed is $\sqrt{r}$, essentially independent of the furnace temperature or drawing force. The heat input controls only the rate of drawing,

whilst the drawing force controls the viscosity or temperature at which the glass is drawn. However, the adjustment of these two factors is not critical. Obviously a minimum furnace power is required for a reasonable rate of drawing; it was also found that a minimum drawing force is required if one wishes to obtain a homogeneous fibre. Other requirements are very low inertia and low friction of all moving parts.

As an example the drum A was made from polyurethane foam, of one metre diameter, and B was a steel shaft, of five millimetres diameter, revolving on tiny ball bearings. The drum B was held by light Bakelite flanges. The furnace consisted of five turns of Kanthal wire (A. B. Kanthal, Hallstahammar, Sweden), 0.9 ohm per metre, wound on a 6 mm diameter mandrel. A glass rod of 1.5 mm diameter gave a continuous fibre of diameter $0.11 \text{ mm} \pm 4\%$ at a rate of 6 metres per minute. The drawing torque was 1200 g cm.

For the initial setting of the process, the glass rod is heated in a flame and drawn by hand in the usual way. The tip of the fibre is then glued to the rim of the drum A with adhesive tape, care being taken to adjust the rod-fibre junction at the correct furnace height. If this junction is too high, the fibre diameter is further reduced and the fibre may break before the process is started. On the other hand, if the junction is too low, the process initiates on the rod after a short delay, leaving a small swelling of glass which can be overlooked in most cases. However, the correct adjustment is not critical and can be achieved easily. Provided the inertia and friction of the system are kept very low, the steady drawing condition is established almost from the onset and a uniform diameter is readily obtained right from the first few millimetres.

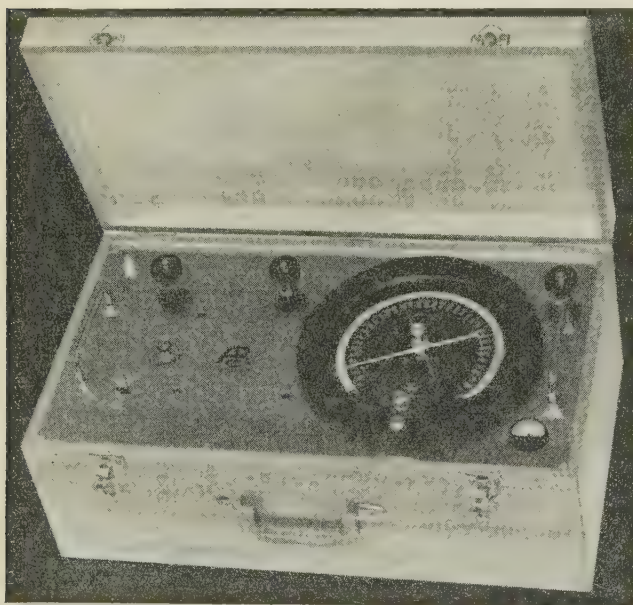
Various improvements may be introduced into this simple arrangement. The weight W may be omitted and the drums driven by a light motor operating through a transmission system adjustable for torque; the latter must be almost independent of the velocity of the system, in order not to interfere with the self-adjusting property of the drawing apparatus. Also, the drum B may be made to move back and forth axially in order to deposit the fibre regularly on its rim. Finally, if B is made eccentric to A, the drawn fibre will have a diameter varying according to a definite, preset, periodic pattern, determined by the form, dimensions and eccentricity of B.

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep her informed of their new or improved products. The Institute of Physics and The Physical Society assumes no responsibility for the statements given below; information for these has been taken from the literature supplied.

Portable pressure pulse calibrator. Atlantic Research Corporation, Alexandria, Virginia, U.S.A.

The calibrator provides pressure pulses of known values for the calibration of pressure transducers and of complete dynamic pressure recording systems. A 1600 lb/in² supply flask contained in the instruments feeds gas, as needed, into a calibration pressure flask which is then connected via a back-seating poppet valve to the active face of the transducer under test. The resulting pulse is claimed to have a rise time of 3 ms from atmosphere to calibration pressure, which can be set from a few inches of water to 1000 lb/in². Pressure on the transducer is vented to atmosphere by releasing the poppet valve, the volume of gas so lost being small enough to allow several pulses at the desired pressure before recharging the calibration flask, and to give negligible adiabatic temperature changes. The calibration pressure is indicated on a



precision Bourdon gauge, having an accuracy and linearity better than 0.1%, which can be provided with scales from 15 to 1000 lb/in² full scale. In addition to adaptors for Atlantic Research transducers, blank adaptors can be fitted to other designs.

Spectrophotometer power supply. Labgear Ltd., Instrument Division, Cromwell Road, Cambridge.

The type 115D transistor stabilized power supply is designed specifically to replace lead-acid accumulators for driving the

tungsten filament lamp and valve heaters of the Unic SP500 spectrophotometer, but it can also be used in other circumstances where a stable 6 v d.c. supply is required.

The unit, which is mains operated, employs a conventional series stabilizer system, a compensating double zener reference being used to provide a high degree of stabilization. It provides output voltages of 6 v at 6 A max, 6 v at 100 mA max and 2 v at 100 mA max. The output resistance is less than 0.005 Ω on the 6 v outputs, and approximately 1.3 Ω on the 2 v output. The stability factor is better than 1000 for input variations of -15% to +20%, and the combined ripple and noise is approximately 3 mv peak to peak.

Particular care has been taken in the design to minimize the temperature rise of the sampling and control components due to the heat dissipation in the series regulators. The use of the latest type power transistors together with cast aluminium heat sinks permits operation in high ambient temperatures and under adverse mains input conditions. First quality components are employed throughout, making the unit suitable for use in all climates.

New electrophoretic support. Gelman Instrument Co., 1 North Main Street, Chelsea, Michigan, U.S.A.

Microphore, a cellulose acetate paper-thin sheet made with 3-micron diameter pores, is a new support material for zone electrophoresis which is claimed to be much superior to paper, giving separations which are sharper and enabling separation of many compounds which cannot be separated with paper.

Complete separation, staining and evaluation of food samples can be achieved in less than an hour. A sample of 0.05 microlitres is sufficient to produce recognizable patterns and as little as 2 microgrammes of protein shows a pattern. Larger quantities can be separated for subsequent recovery and individual bands can be cut up and dissolved in solvent for further investigation. Identical samples are reproduced to within 1%. The material is chemically inert, absorbs only sample only to a negligible extent, and has high wet and tensile strength. It can be made transparent for optical evaluation, the transmission through unstained portions being uniform to 1% or better. The material is available in a wide variety of sizes, ranging from 1.25 cm $\times$ 12 cm to 20 cm $\times$ 50 cm.

Electromagnetic vibrators. Magco Ltd., Lake Worth, Portchester, Hants.

In the newly designed Magco electromagnetic vibrators the ratio of moving to fixed weight has been reversed, so that the moving weight, which is a casting carrying the laminations and coil, is twice as heavy as the fixed unit which carries the armature. It is claimed that this results in a considerable increase in efficiency and a reduction in cost because repetitive production methods are possible. The vibrators have uses for consolidating materials before packaging, and also for assisting the flow of material from hoppers or down chutes.

A wide variety of sizes is available, ranging from units suitable for use on the smaller pharmaceutical packaging machines to units adequate for bunkers holding hundreds of tons. With a 50 c/s supply the smaller units vibrate at 100 c/s and the larger units at 50 c/s. The absence

aring parts obviates the need for lubrication; and water-tight covers, and for most sizes flame-proof coverings and air associated flame-proof control gear, can also be supplied.

Stripping agent for removing epoxy and polyester resins. Narmco Industries, Inc., 600 Victoria Street, Costa Mesa, California, U.S.A.

le-Solv G is a new gelatinous self-activating stripping agent which will remove epoxy and polyester-based coatings. It is applied by brushing or spreading and adheres to all surfaces, contoured or vertical. It begins its stripping action on application, and dries quickly. When the part is stripped as required, the residue is easily removed, after which the part can be worked on immediately without sanding or further treatment. It is non-flammable and non-acidic, and will not corrode or damage copper, aluminium or ferrous metals.

Precision spiroid gears. P.I.C. Design Corporation, 477 Atlantic Avenue, East Rockway, Long Island, N.Y., U.S.A.

A range of precision spiroid gears and pinions, in $\frac{1}{8}$ in., $\frac{1}{4}$ in., and $\frac{1}{2}$ in. shaft sizes, is available for immediate delivery. It is claimed that the multi-tooth contact design provides inherent precision unobtainable with other forms of low contact-ratio gearing, giving advantages in back-lash control, shock strength, noise level and accuracy for high-ratio, right angle gearing applications. A 24-page catalogue containing complete information is available free from the manufacturers.

Frequency meter and discriminator type 1142-A. Claude Lyons Ltd., Valley Works, Hoddesdon, Herts.

This product of the General Radio Co., U.S.A., is of the pulse-counter type giving readings which are independent of input signal waveform, and has a total coverage of 3 c/s to 1.5 Mc/s. A constant reading accuracy of 0.1% is obtained by means of a logarithmic meter scale which can be off-set in 15 calibrated steps on each of the 5 basic ranges. Input sensitivity is 20 mv and residual noise is 100 db below full output. A d.c. output is provided to operate a recorder for frequency-drift measurements. With the aid of a wave analyser, incidental frequency modulation can be measured down to 1 part in 10^6 directly, and down to 1 in 10^9 by indirect methods.

Vibration limit controller. Dawe Instruments Ltd., Harlequin Avenue, Gt. West Road, Brentford, Middx.

The type 1434 Vibration Limit Controller provides continuous protection for large rotating machinery against failures due to excessive vibration. Provision is made for operating an external warning lamp or bell and for switching off the machinery at any predetermined vibration level. A direct reading meter indicates the actual level and an output signal is available for operating an external recorder. The moving-coil pickup, which is hermetically sealed in nitrogen, can be located up to 200 ft or more from the control unit.

The meter is calibrated in peak values of displacement for simple harmonic motion applied to the pickup. Four ranges are provided having full scale readings of 0.001, 0.003, 0.010 and 0.030 in. respectively (or alternatively 0.03, 0.10, 0.30 and 1.0 mm). The warning level can be set anywhere between 20% and 100% of full scale on any range, for which purpose an internal injection signal is provided. Once the alarm circuit has been tripped it remains operative

until reset manually. A delay network is incorporated to prevent the alarm being operated by unrelated transient shocks, the delay being such that 5% excess vibration maintained for about 7 sec, or 20% for about 3 sec, is necessary to effect operation.

The control unit is 10 in. $\times$ 14 in. $\times$ 9 in. and the pickup is $2\frac{3}{4}$ in. long and $1\frac{1}{4}$ in. diameter.

Vibration pickup system type 1560-P11. Claude Lyons Ltd., Valley Works, Hoddesdon, Herts.

The General Radio Sound-level Meter Type 1551 can be used as a vibration meter by the addition of Vibration Pickup System Type 1560-P11, which comprises an accelerometer and associated control box. The accelerometer is a barium titanate device having an output linear up to 100 g and a nominal sensitivity of 40 mv/g which is claimed to vary less than $\pm 10\%$ over the temperature range 30–180° F. The control box contains a preset gain control, adjusted at the factory to match the pickup sensitivity to that of the meter, and integrating circuits to provide velocity and displacement readings. Maximum values of such readings are a function of frequency and are determined by the 100 g limit. At 20 c/s, for example, the respective maxima would be 307 in/s and 2.44 in.

Norma light-spot fluxmeter. Croydon Precision Instrument Co., Hampton Road, Croydon, Surrey.

The Model 251F Fluxmeter, which is a product of Fabrik elektrischer Messgeräte Norma GmbH, Vienna, is a portable ballistic galvanometer having 10 sensitivities from 500 to 500 000 Maxwell turns per division. The scale is 6 in. long and has 150 divisions numbered 30–120. The instrument employs a D'Arsonval system with a taut-ribbon suspension whose torque is counteracted by a small piece of diamagnetic material located within the field of the Alnico core magnet. The light beam provides a pointer length of one metre and the light spot is visible in full daylight by virtue of a cylindrically ground mirror in the optical system. The light source is a special 4-volt bulb, powered either by an external battery or transformer, which also illuminates a photo-element providing the energy to return the pointer to zero. When using a 30-ohm search coil the accuracy of the meter is claimed to be within $\pm 1\%$ provided that the integrating time lies between 1 millisecond and 1 second. The die-cast aluminium case measures 8 in. $\times$ 10.5 in. $\times$ 5.3 in.

Computer for measuring the integrated flow of liquids and electrical power. Radiatron, 7 Sheen Park, Richmond, Surrey.

To facilitate central supervision and control, the following installations for the digital indication and printing of measurements has been designed. The measurements include the integrated flow of liquids, e.g. oil and water, and gases, e.g. steam and compressed air, and electrical power. The device is designed to fulfil the need for automatic plant supervision where more complicated electronic computers are not justified.

The equipment operates from instruments producing an electrical pulse or switch closure for each unit consumed. It is based on the 'Kienzle' transistorized digital printer and uses counter stores which retain their information in the event of a mains failure.

Pulses from the measuring instruments are integrated in the stores, each single channel representing a plant department or a particular type of fuel. The accumulated pulses in each channel are displayed continuously on electro-mechanical

registers or in-line indicators. A programming unit initiates printing at pre-set times in some or all of the channels and includes switches for each channel to select either totalizing, or re-setting to zero, after printing.

Two types of print are available, the printing speed of each is about 2 channels sec^{-1} and the printer can print up to 14 digits in parallel, and it can change over instantly from black to red. The date and time can also be printed.

The programming panel contains a digital clock, and, for each channel, a reset push button and a 7-way switch allowing the preselection of 1 hr, 8 hr or 24 hr intervals (with or without zeroing the store) or 'no print'.

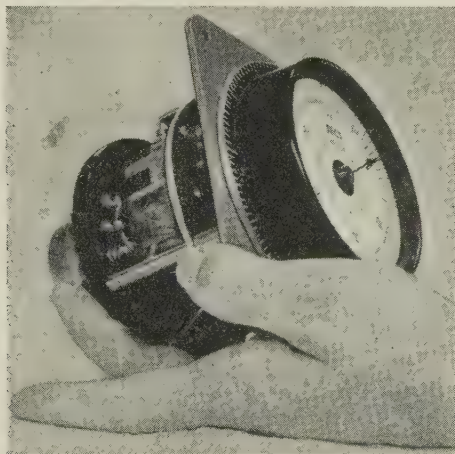
Balance. Baird and Tatlock (London) Ltd., Freshwater Road, Chadwell Heath, Essex.

A balance operating without knife-edges and friction is available from this firm. Known as the Torbal balance, its principle is to have a counterpoise weight above the fulcrum, so that the centre of gravity of the balance is above the fulcrum. A slight inequality of the weights on the scale pans produces a displacement towards the heavier side. The movement is finally arrested by the torsional resistance of supporting bands. There are no loose parts on the balance and therefore no deterioration due to wear or accumulated dust.

Several models are available, ranging from a capacity of 120 g and a sensitivity of 3 mg to a capacity of 4500 g and a sensitivity of 0.2 g.

Self-resetting synchronous timer. Electrical Remote Control Co. Ltd., Bush Fair, Harlow, Essex.

A solenoid operated electromagnetic clutch couples the timing cam and pointer to a miniature synchronous motor in this timer, which is reset automatically within 0.5 second when the clutch is de-energized. The required time is pre-set by rotating the bezel and the timer is started within 0.1 second by a push button impulse or by switching on the supply. Two basic types, STAR and STAR/D, respectively provide contact operation during or after the preset time, each type



being available with one of 15 time ranges from 0–12 seconds to 0–24 hours. Switching capacity is 5 amps at 240 volts a.c. or 0.5 amp at 440 volts a.c. Timers are available for use on supply voltages of 110, 200–240 (50 or 60 c/s) and 400–440 (50 c/s). The timer is mounted in a panel 5 in. square and has an overall depth of 5½ in.

X-ray spectrometer control panel. Philips Electronic Instruments, 750 South Fulton Avenue, Mount Vernon, N.Y., U.S.A.

This control panel is designed for use with Norelco Diffractometer and Spectrograph installations.

The panel contains power supplies for two radiations detectors and a pulse height analyser, which measures intensity of the x-ray spectrum in a selected energy range.

Automatic control of the position of the detector with respect to the x-ray source is provided for use with external goniometer.

There are two ratemeters, one linear and one logarithmic, either may be used to drive the strip chart recorder.

The counter with Dekatron counters and a 1 Mc/s decade stage giving resolution of 1 μs may be set for the following operations: count continuously with ratemeter monitoring counting rate; count for a fixed period, measured in hundredths of a second; count a selected number of counts and indicate elapsed time in hundredths of a second. counter output may be recorded on a decimal printer.

Linear amplifier gain is adjustable, resolution is 1%, linearity $\pm 2\%$. The linear ratemeter has an accuracy $\pm 1\%$ and time constants of 0.5, 1, 2, 4, 8, 16 seconds. output is adjustable to give full scale pen recorder deflection of 100–200–500–1000–2000–5000–10 000–20 000–50 000–100 000–200 000 or 5000 000 counts per second.

The logarithmic ratemeter provides 10 to 2000 000 counts per second with an accuracy to $\pm 5\%$, the time constant varies automatically to adjust for counting rate. The output is read on a front panel meter or used to drive the strip recorder.

All internal power supplies are stabilized, and in addition two stabilized outputs for counters are provided, one 650–1500 volts, the other 1400–3000 volts, both continuously variable. Reproducibility of output is better than 0.1%, ripple 0.002% max, stability 0.1%, regulation against 10% mains change is 0.1%.

Input is 90–260 volts a.c. and an internal mains voltage regulator is included.

The complete panel is 20½ in. wide, 51 in. high and 22 in. deep.

Thermoelectric cooling unit. The General Electric Co. Ltd., Magnet House, Kingsway, London W.C.2.

The B.T.4 thermoelectric cooling unit is the first of a projected range of units to be readily available. Based on the Peltier effect, it has a cooling capacity rated nominally at 1 watt, although the rating can be increased with a resultant reduction of the temperature depression, or alternatively a greater temperature depression can be achieved by reducing the rating. It is made in the shape of a small cube, and thermoelectric junctions are formed by a combination of p and n type bismuth telluride. In use the block is clamped between the object to be cooled and a heat sink.

Typical applications are the cooling of electronic components which must operate in high ambient temperatures when it serves to increase the power rating of transistors, reduce the dark current of photo-transistors, or to allow the operation of quartz crystals at a selected point of the frequency deviation–temperature characteristic. Other applications include the cooling of small volumes by incorporating one or more units into the walls of a chamber, in which the temperature may be held constant by a proportional controller which allows smooth regulation of the cooling rate by means of the current supplied.

The Craftsmanship and Draughtsmanship Competition of The Institute of Physics and The Physical Society

In these days of mass production it is a matter of some concern that craftsmanship is dying. This is seen in the countryside as well as in the town—there are few men who can thatch, few men who can lay a hedge and, in the instrument world, there are fewer men who can make instruments with their own hands.

At first sight it might be said that there is no demand for craftsmanship in the making of instruments—mass production is more rapid, more exact and more valuable commercially. Have you thought, however, how the first instrument is made

participated in The Physical Society Exhibition. It was felt at that time to be of value to encourage young fellows to show what they could do and to compete one against the other in a friendly manner. During these early years the Competition gained in strength until at the beginning of the war it had grown in size from an entry of 53 in the first year to 105 in 1939.

During the war it was not possible to continue with the Competition, but in 1948 the suggestion that it be restarted was met with enthusiasm both by the firms who were entitled

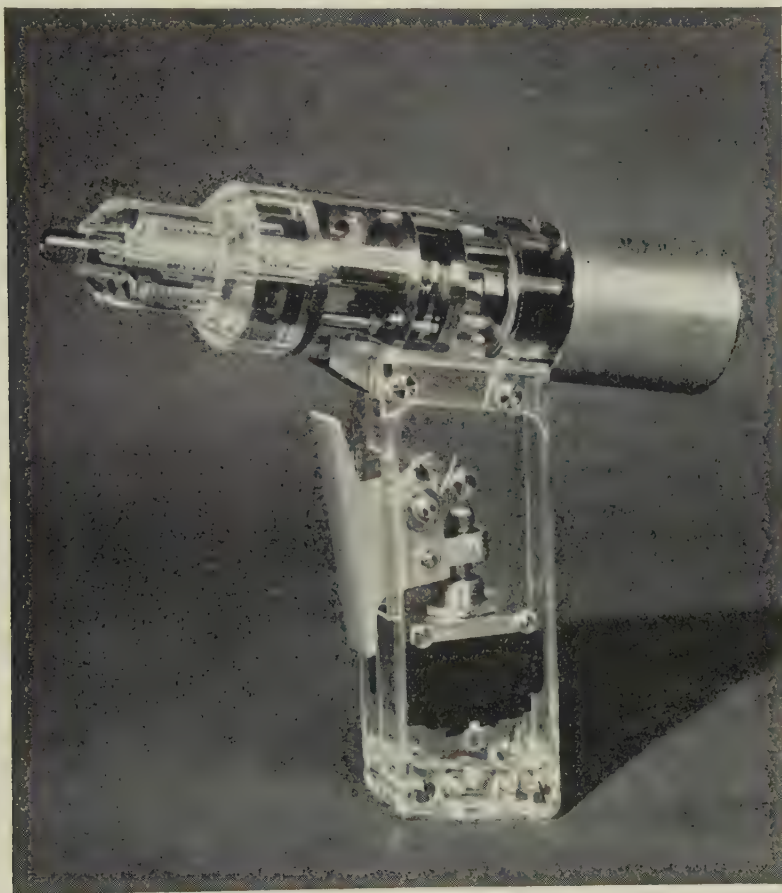


Fig. 1. Class I, Silvanus P. Thompson Prize, and Class II, 1st Prize (Senior Grade)—John S. Palmer, 21 years, of Marconi's Wireless Telegraph Co. Ltd. Reset Motor Assembly.

from which the mass produced form is finally developed? This must be the work of someone skilled in the art of visualizing what is required for any specific job, devising the best method of doing it and making the instrument in all its fine detail.

The Craftsmanship and Draughtsmanship Competition, organized by The Institute of Physics and The Physical Society, was instituted by The Physical Society in 1929 for the apprentices and learners employed by firms which had

to participate and by the judges who had officiated before the war. In the first year the entries totalled 89 and this good response encouraged the Society to continue and to develop the Competition.

The Craftsmanship side of the competition was originally divided into sections to cover scientific instruments and components, tools and gauges, optical components and systems, blown glass and silica ware, patterns and functional scale models of scientific interest. The Draughtsmanship

section was intended to show general arrangement diagrams and detailed and dimensioned drawings, copies of which would be suitable for workshop use.

Prizes were awarded in all these sections and there was one special prize, known as the Silvanus P. Thompson Prize, which was presented by the old Finsbury Technical College (the forerunner of the City and Guilds Engineering College) in memory of their Professor, Silvanus P. Thompson, who had, incidentally, been a President of The Physical Society. This prize was awarded for an entry which consisted of an instrument or component and the working drawings from which it had been made, both parts of the exhibit having been prepared by the competitor.

In the course of time it has been found that some of these earlier sections are no longer closely applicable to the development and production of scientific instruments of

Institute and Society itself and Certificates of Honour and Mention are awarded to those not quite up to prize standard.

The standard of this competition is extraordinarily high, especially considering the age of the competitors, who are 16–19 in the Junior Class and 19–22 in the Senior Class. Indeed the standard has been such that the Committee of Judges last year decided to institute further Certificates of Merit, which were awarded to every entrant whose work was of a sufficient standard to be displayed at the Annual Exhibition, and this year all but one of the entrants received either a certificate or a prize. The photographs, Figs 1–4, show typical entries in this year's Competition.

One departure from normal practice this year was in co-operation with the Science Museum who, needing scientific reproductions of early scientific instruments for their historical section, invited entrants to our competition to make from original instructions and drawings some reproductions of these early instruments. One such instrument was submitted and gained a first prize. This was a reproduction of a Sixteenth Century Assayer's Balance submitted by Mr. Haynes of L. Oertling Ltd., and is shown in Fig. 5.

In the past the Competition has been organized entirely in conjunction with The Physical Society Exhibition, but now that the Society is amalgamated with The Institute of Physics it has been agreed unanimously that the Craftsmanship and Draughtsmanship Competition should be one of the responsibilities of the Education Committee of the joint body, the Institute of Physics and The Physical Society. The regulations for it are remaining exactly as before and it is the earnest hope of the Committee and Council that more and more young lads and girls will enter for this Competition.

The purpose of this article is to bring the Competition to the attention of readers who may have apprentices or o-

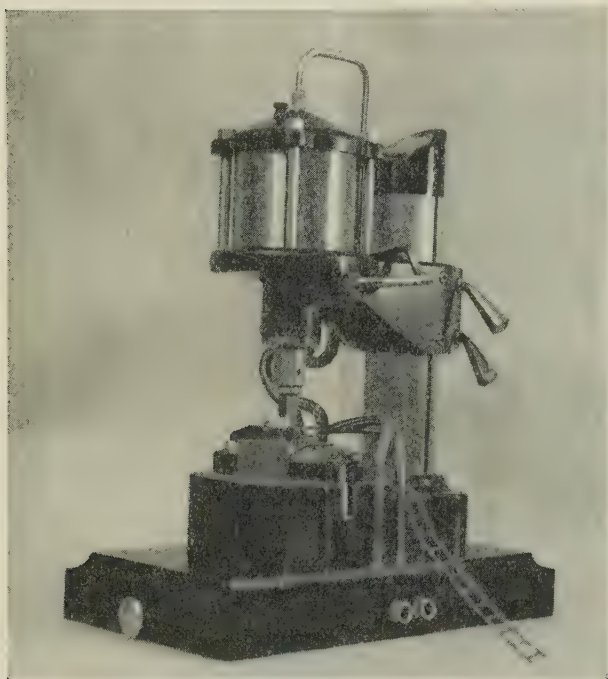


Fig. 2. *Class V, 2nd Prize*—Roger Fry, 20 years, of Standard Telephones and Cables (Newport). Pneumatic Press.

interest to The Physical Society, and the sections for Tools and Gauges and for Draughtsmanship by itself have been removed. The Tools and Gauges section is covered by the competition of the Gauge and Tool Makers' Association and it was considered that the straightforward workshop drawings were also not of great value for the purpose of the Competition. In place of these two sections new ones have now been included, one for Microwave Components and one for Electronic Circuitry, both subjects which have developed markedly since the end of the war. We have also instituted a section for a combination of craftsmanship and draughtsmanship in addition to that already present under the Silvanus P. Thompson Prize. This new section is intended for the younger competitors so that competitors of all ages do in fact have a chance of showing their prowess in combined craftsmanship and draughtsmanship.

In addition to the special Silvanus P. Thompson Prize, referred to above, special prizes are awarded from the Bowen Trust Fund by courtesy of the Scientific Instrument Manufacturers' Association. Further prizes are given by the

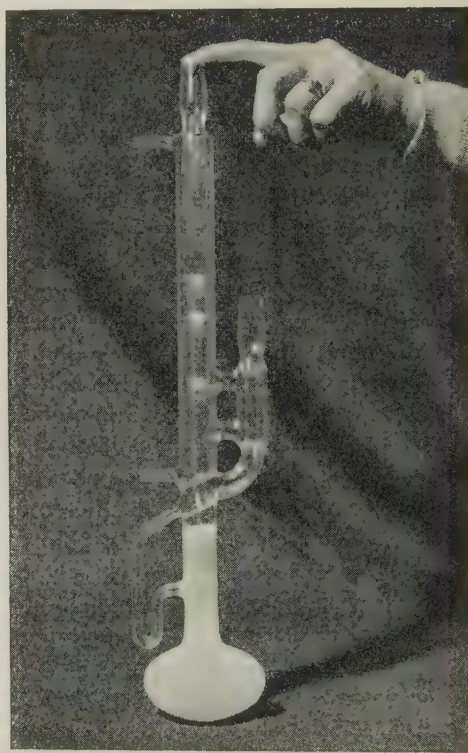


Fig. 3. *Class IV, 1st Prize, Section (b)*—William Moncrieff, 21 years, of The Thermal Syndicate Ltd. Mercury Condensation Pump.

ing staff in their laboratories who might be encouraged to part. It is stressed that it is not only employees of firms research associations connected with the Exhibition who eligible for this Competition, but also employees in workshops or drawing offices of educational establishments and

special piece of apparatus made by an instrument maker in one of these establishments.

The items for submission may be selected by the competitors themselves to fit in the sections we have mentioned and work may start at any time from now onwards, to be

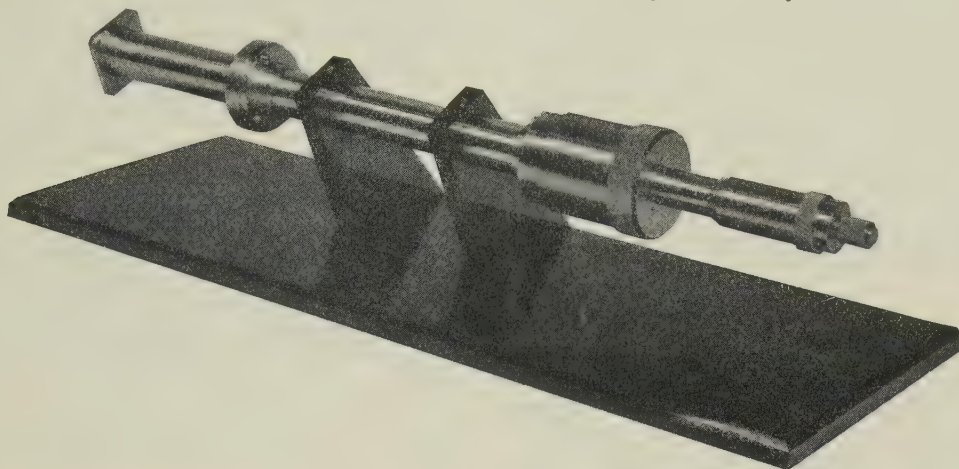


Fig. 4. Class VII, 2nd Prize (Senior Grade)—Allan E. Pembroke, 21 years, of Mullard Research Laboratories. Impedance for 3 cm Waveguide.

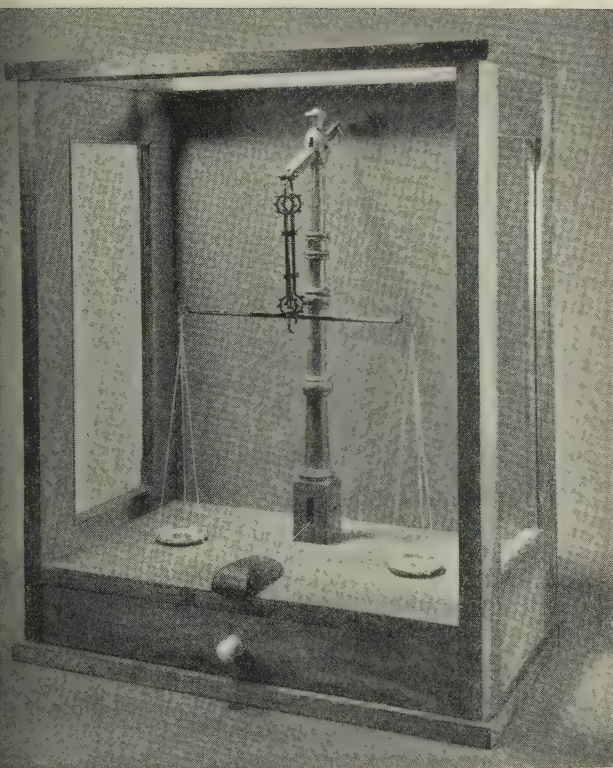


Fig. 5. Class V, Special Prize—Melvyn J. Haynes, 21 years, of L. Oertling Ltd. Sixteenth Century Assayer's Balance.

ments attending recognized workshop or machine-drawing courses at technical colleges or technical schools. One section which we would like to expand is for work by the senior people, particularly those working in University Laboratories, Hospitals and Technical Colleges. For this we have a section for Research Items which may include any

ready by the beginning of December. Competitors have to state how long they have taken on the job—the average is of the order of 200–300 hours' work.

Summary of Classes in the Competition

- I. Silvanus P. Thompson Prize for Draughtsmanship and Craftsmanship combined. A scientific instrument or component together with a complete working drawing, open to both junior and senior competitors.
- II. Scientific Instruments and Components.
 - (a) Junior Grade.
 - (b) Senior Grade.
 - (c) Advanced Grade (up to 26 years of age).
- III. Optical Components and Systems.
- IV. Blown-glass and Silica Ware.
 - (a) Glass Work.
 - (b) Silica Work.
- V. Instructional Items, Sections of Instruments, Functional Scale Models of Scientific Interest and Patterns.
- VI. Items showing Draughtsmanship combined with Craftsmanship.

Junior Grade only.
- VII. Microwave Components.
 - (a) Junior Grade.
 - (b) Senior Grade.
- VIII. Electronic Circuitry.
 - (a) Junior Grade.
 - (b) Senior Grade.
- IX. Research Items. Limited to entrants from University Laboratories, Hospitals and Technical Colleges.
 - (a) Junior Grade.
 - (b) Advanced Grade (no age limit).

Further details about the Competition are available from either of the Institute and Society's Offices.

Notes and comments

175 years Verlag Friedr. Vieweg & Sohn, Braunschweig

On 1st April 1786, Friedrich Vieweg established the publishing house which still bears his name today. During its latter years the firm has mainly dealt with the publication of books and periodicals in the field of mathematics, natural sciences and engineering, and with mathematical-scientific textbooks and special books. On the occasion of their 175th anniversary the publishing house is giving prizes for important papers in the field of mathematics, physics and chemistry, suitable for publication in book form. Details concerning the conditions for the competition may be obtained from Friedr. Vieweg & Sohn, Braunschweig, Burgplatz 1, Germany.

Soviet Astronomy—AJ

Soviet Astronomy—AJ is a translation beginning with the 1957 issues of the *Astronomicheskii Zhurnal* of the USSR Academy of Sciences. It appears bimonthly and is published by the American Institute of Physics in co-operation with the National Science Foundation. The main subjects covered are: astrophysics and radio astronomy; stellar astronomy; the solar system; satellites, interplanetary medium and geophysics; and instrumentation.

The journal is available from the American Institute of Physics, 335 East 45th Street, New York 17, N.Y. The price is \$27.

Thomson lecture of the Society of Instrument Technology

The Council of The Society of Instrument Technology have decided to inaugurate an Annual Lecture on a general subject. The first President of the Society, Sir George Thomson, M.A., F.R.S., Master of Corpus Christi College, Cambridge, has not only consented to give his name to this lecture but also to deliver the first one.

This will be at 6 p.m. on Thursday, 19th October 1961, at The Royal Institution. Admission will be by ticket only. Further details will be available later from the Society.

Digest of Literature on Dielectrics

A comprehensive international digest of technical publications on the theory and applications of dielectrics and related subjects has been prepared and published annually by

the *Digest* Committee of the Conference on Electrical Insulation of the U.S.A. National Research Council. The *Digest*, prepared by a group of 38 experts, covers all aspects of dielectrics and treats the subject from the point of view of the physicist, the chemist and the engineer.

The *Digest* contains summaries and evaluations of technical advances in various phases of the field which were described in periodicals and books published in 1959. It consists of twelve chapters, each with an extensive bibliography, covering different aspects of dielectrics: Instrumentation and measurements; Tables of dielectric constants, dipole moments, dielectric relaxation times; Molecular and ionic interactions in dielectrics; Conduction phenomena in solid dielectrics; The breakdown of dielectrics; Ferroelectric and piezoelectric materials; Magnetic materials; Rubber and plastic insulating materials; Insulating films and fibrous materials; Insulating liquids and their applications; Solid inorganic insulation; Applications.

The *Digest* consists of 421 pages, including a bibliography of 2,200 references. The price is \$8.00.

British Journal of Applied Physics

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Improved fluorimeter for uranium analysis

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received 11th November 1960

Abstract

stable fluorimeter, easily operated and serviced, has been developed. Drifts are reduced to a minimum by measuring only the alternating component of the fluorescent light. The exciting ultra-violet radiation is held at a constant level by a special light-stabilizing circuit. The radiation remains stable within $\pm 1\%$ for power line variations over the range of 200–250 v. The initial warm-up is less than 3 minutes compared with 10–15 minutes without the light-stabilizing circuit. The sensitivity of the instrument is to better than 10^{-9} gramme uranium per fused pellet.

Introduction

THE fluorimetric microanalysis of uranium is based on the measurement of the fluorescent light emitted from a sample excited by intense ultra-violet radiation. The intensity of the secondary light is proportional, over a wide range, to the uranium concentration and the intensity of the exciting radiation (Price *et al.* 1953). A fluorimeter will therefore give a quantitative indication of the uranium content of the sample tested, provided that all instrument parameters remain constant. The sensitivity limit of many instruments is about $10 \text{ m}\gamma$ ($1 \gamma = 10^{-6}$ gramme), only the more elaborate and hence expensive ones enable analysis of uranium in much lower concentrations (Oster 1953, Galvanec and Morrisson 1954). The new fluorimeter developed had to be sensitive enough to measure concentrations of less than $1 \text{ m}\gamma$, to be very small, to be simple to service and not have critical electronic components or circuits. The intensity of the exciting radiation in the instrument described is held at a constant level by a closed-loop regulating circuit. The light-stabilizing circuit was specially devised for this instrument. A synchronous detector with only a very small bandwidth eliminates most errors due to photomultiplier noise and ripples.

1. Block diagram (Fig. 1)

The fluorimeter consists of two main parts, the measuring circuit and the light-stabilizing circuits.

The radiation of the ultra-violet lamp Lp excites the sample S to fluorescence. The intensity of the fluorescent light is measured by the photomultiplier Pm. A detector Det rectifies the photomultiplier output and feeds it to the meter circuit M.

The light-stabilizing circuit is driven through a beamsplitter Bsp by a small fraction of the ultra-violet radiation. The light is held constant. A photoelectric cell C controls the power of the ultra-violet lamp via a transducer Tr and its control tube Ct.

Two auxiliary parts, the power supply Psp and the frequency

doubler Fd which furnishes a reference signal to the detector, are included in the instrument.

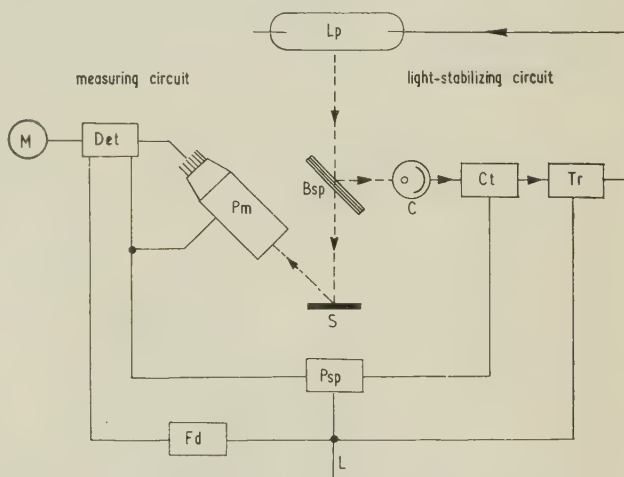


Fig. 1. Block diagram.

Lp, ultra-violet lamp; M, meter; Bsp, beamsplitter; Fd, frequency doubler; S, sample; C, photoelectric cell; Det, synchronous detector; Ct, control tube; Tr, transducer; L, line; Psp, power supply.

2. Optical and mechanical construction

2.1. Light source

An ultra-violet lamp type T/M5/577/0, made by the Thermal Syndicate, was selected by virtue of its small dimensions (11 mm in diameter and 110 mm long). The arc in the lamp is struck by an external electrode fed from a small 2500 v transformer. The transformer primary is connected to the power line via a 30-second thermal delay relay. Relatively long excitation of the igniter is necessary, as the light-stabilizing circuit takes a few seconds to warm up and gain control over the lamp.

2.2. Optical path (Fig. 2)

Two optical filters Bsp and F_1 (Corning No. 5840) limit the radiation of the lamp Lp to that part of the spectrum in the ultra-violet region which is best suited for the excitation of uranium. Five stops D_1 – D_5 minimize the reflections from the blackened walls of the tube T and confine the light pencil to the near vicinity of the sample. No quartz lenses are used, as stops are much cheaper and are quite adequate for the purpose. About 15% of the total ultra-violet radiation is reflected by the forward surface of the filter Bsp into the direction of the photoelectric cell C, the first element of the light intensity stabilizer.

The greenish fluorescent light passes a composite filter F_2 (Corning Nos. 3486 yellow, 4445 blue, 7910 ultra-violet absorbing) before it strikes the photomultiplier Pm. This filter stops all ultra-violet radiation which may stray into the path of the fluorescent light.

2.3. The sample

The uranium to be analysed is contained in a pellet of sodium fluoride fused in a platinum dish of 10 mm diameter. The fluorescence of the sample is proportional over several decades to the uranium concentration, provided that the crystal structure of the melt remains unaltered (Lynch and Baumgardner 1955). The main factors affecting the fluorescent yield are atmospheric conditions, method of preparation and the time elapsed between preparation of the melt and measurement. These factors are dealt with in the extensive literature (e.g. Price *et al.* 1953, Lynch and Baumgardner 1955, J. T. Byrne (Dow Chemical Co. Report 65)).

2.4. Sample carrier (Fig. 2)

The sample carrier is a heavy brass disk H with 12 depressions near its outer circumference for the samples. A

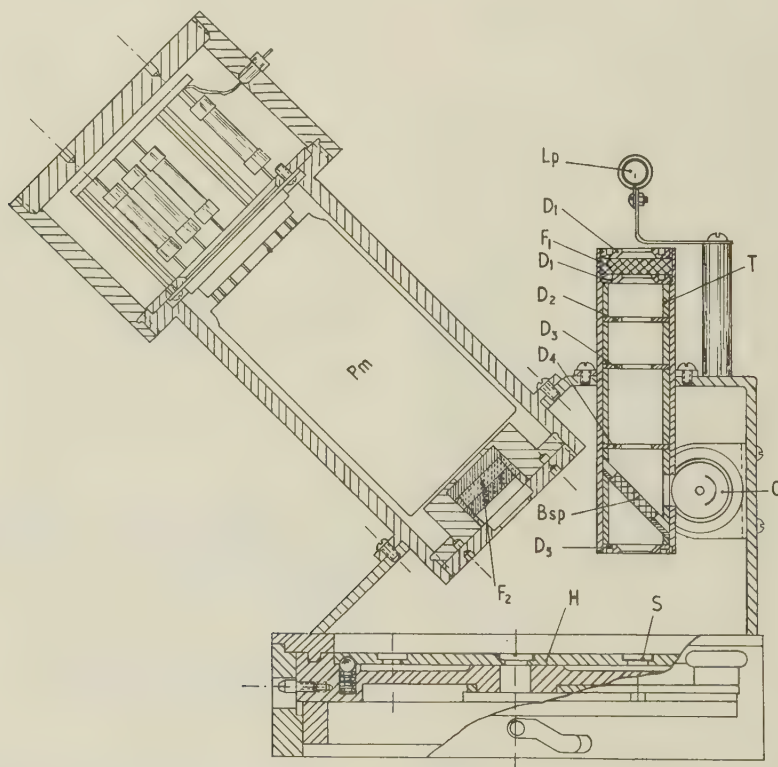


Fig. 2. Mechanical design of optical parts and sample carrier.

simple ratchet mechanism rotates the disk, bringing the consecutive samples into the measuring position. The carrier is 'loaded' with samples while taken out of the instrument. This simplifies sample insertion and accelerates the testing of large quantities. Light leakage is eliminated by locking the carrier to the lower part of the sample chamber. Small inaccuracies in sample positioning will not influence the measurement as the light pencil is somewhat larger than the sample diameter.

3. Measuring circuit

3.1. Photomultiplier

A type 9502 E.M.I. photomultiplier was selected as it has low noise and high electron multiplication with an open-circuit noise current of less than $0.006 \mu A$. Careful positioning of the multiplier in the instrument minimizes magnetic pick-up, while electric ones are eliminated by the brass tube-housing.

No additional electronic amplification is required as the multiplier sensitivity of 2000 A/lm guarantees output signals of several volts over a wide range of uranium concentrations. A conventional cathode follower matches the photomultiplier impedance to that of the detector input transformer. A multi-position attenuator R with a 1-3-10 sequence changes the overall sensitivity of the instrument from 1 m μ to 100 μ g uranium for full-scale deflection.

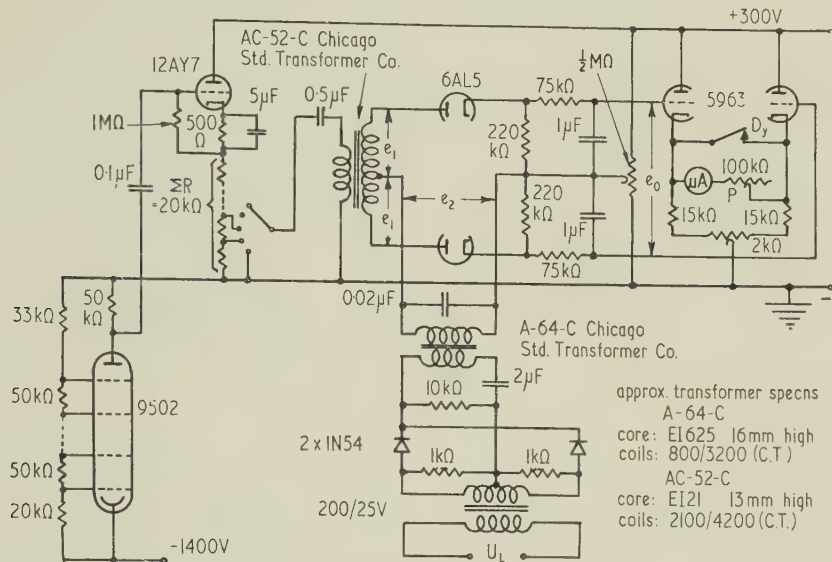
3.2. Synchronous detector

The photomultiplier output contains, in addition to the desired 100 c/s signal, noise components due to pick-up and the photomultiplier itself. There are at least two possible ways to eliminate these unwanted signals: (1) band pass filters such as twin T's, etc.; (2) correlation filters. Filters of the

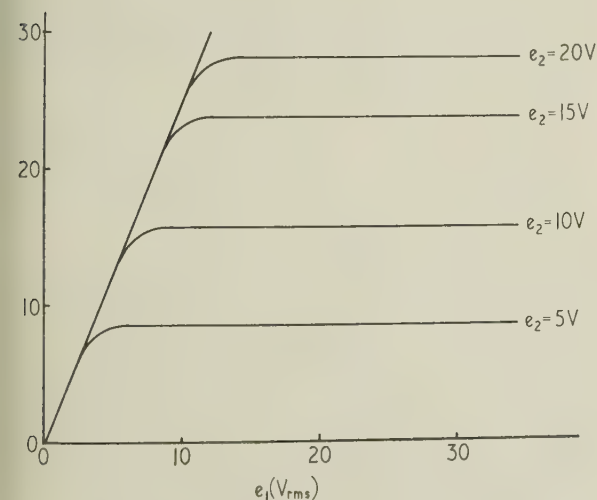
first type are not suitable as they should have a relatively wide bandwidth in order to cope with signal frequency variations due to line frequency instabilities. A small variation in any of the filter components may well make them useless, as these filters are sensitive to component values.

A phase-sensitive detector was selected as it is unresponsive to component values (Fig. 3). Over-all detector bandwidth is governed solely by the subsequent smoothing time constant. An additional advantage of a synchronous detector is

An indicating meter is fed by a balanced pair of cathode followers. A 30-second time delay relay Dy shorts the meter during the initial warming up period. The overall calibration of the fluorimeter is reset daily against a standard sample of known fluorescence by means of potentiometer P.



input $e_1 = E_1 \sin \omega_1 t$ is synchronous to the reference voltage $e_2 = E_2 \sin \omega_2 t$ and at proper phase relation to it. The difference between the two frequencies ω_1 and ω_2 is much smaller than the smoothing filter time constant and the mechanical response of the measuring instrument, meter fluctuations at beat frequency will occur. The detector acts as a very sharp filter suppressing all signals uncorrelated with the reference frequency. The a.c. reference voltage is supplied by a simple full-wave rectifier whose filter circuit is usually tuned to twice the line frequency. No special voltage calibration is required as the frequency multiplier output e_2 is always larger than the signal e_1 to be measured. Characteristics of a detector such as used in the instrument are shown in Fig. 4.



4. Light-stabilizing circuit

As the intensity of the fluorescent light changes with the exciting radiation, steps have been taken to stabilize the ultra-violet source. Without this, frequent readjustments of the fluorimeter would be necessary. There are several ways of obtaining the required stabilization:

- (a) A constant voltage transformer is the regulating component in many currently used fluorimeters (e.g. Byrne (Dow Chemical Co. Report 65), Dawdall 1954). Constant voltage transformers regulate the lamp voltage, but not the ultra-violet radiation emitted.
- (b) Photomultiplier dynode or h.t. supply voltages are varied in accordance with the ultra-violet radiation as measured by an additional photomultiplier. These circuits require two multipliers and a supplementary regulating circuit (Nelson 1952, Brealy and Ross 1957).
- (c) Two simultaneous measurements are made, one of the sample and one of a known standard. These two are equalized by insertion of an attenuator in the reference channel. The attenuation is a measure of the uranium concentration sought. Two amplifiers and an additional servo mechanism are needed.
- (d) The ultra-violet intensity is held at a predetermined level. A photocell measures the ultra-violet radiation and regulates the power supplied to the lamp. This stabilizing circuit is used in the fluorimeter described (Fig. 5).

A known portion of the ultra-violet radiation is measured by an additional photoelectric cell. This cell varies the control current of a saturable reactor through a single stage

electronic amplifier. The reactor regulates the power supplied to the lamp and hence the ultra-violet radiation intensity. The average ultra-violet emission is determined by the preset static bias U_g of the type 6CG7 control tube.

amplifier and the 85A2 reference tubes are low, as the positive side of the supply is earthed. This connection simplifies the layout and wiring and also ensures proper photomultiplier functioning. A VR stabilization of

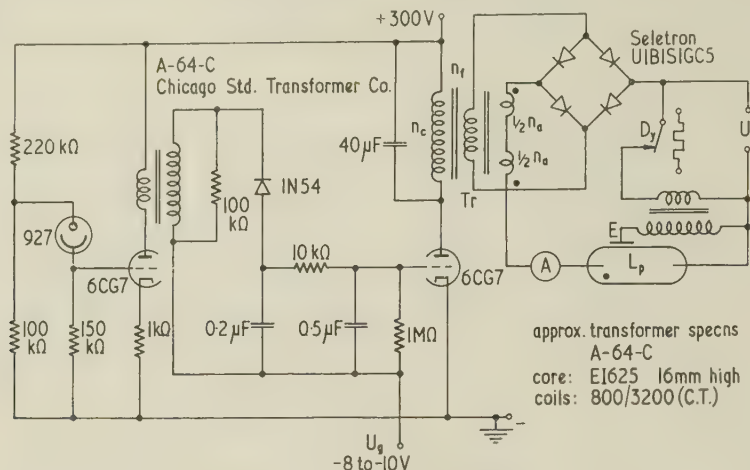


Fig. 5. Light-stabilizing circuit.

Some aspects dealing with the design of the transducer and its performance are dealt with in the appendix.

4.3. Circuit performance

Reaction time. The corrective reaction of the circuit to a change in the ultra-violet radiation should be fast, to minimize measuring errors. Most important are the delays introduced by the transducer, the arc and the smoothing filter in the grid circuit of the control tube. The circuit takes about 150 ms to readjust the radiation intensity to the preset value.

Stabilization. The radiation of the ultra-violet lamp is held constant to within $\pm 1\%$ for supply variations of $\pm 10\%$. This stability is maintained for ultra-violet lamp powers in the range of 50–150 w.

Initial arc stabilization. The initial warming-up period of the arc is shortened considerably as the arc current is increased to about twice its normal value by the regulator action. The ultra-violet radiation reaches its final intensity after about 2 minutes.

5. Power supplies

The output of the electronically regulated e.h.t. photomultiplier power supply (Fig. 6) is variable over the range of 1300–1450 v with less than 6 mv peak-to-peak ripple for currents up to 5 ma. The potentials of the 12AX7 differential

300 v h.t. supply for the measuring and light-stabilizing circuits is adequate. Both supplies are designed for $\pm 10\%$ line voltage variations.

6. Long term stability of the fluorimeter

Deterioration of the sensing element alters the response of every closed-loop circuit. The sensor in the light-stabilizing circuit is a photoelectric cell which may age and change characteristics. An additional factor which influences the arc intensity and varies the overall sensitivity of the instrument is the collection of dust on the filters. The light-stabilizing circuit reacts to these two effects as if the arc intensity has been lowered, e.g. by increasing the ultra-violet radiation. No permanent compensation is possible and recalibrations against a standard of known fluorescence are required.

Conclusion

The fluorimeter is designed to test large numbers of uranium samples. The special light-stabilizing circuit holds the exciting ultra-violet radiation at a predetermined level. The fluorimeter, being an a.c. instrument, is inherently stable and free from zero drifts. All pick-ups and erratic signals not at the measuring frequency (100 c/s) are filtered out by a synchronous detector and do not influence the fluorimeter reading.

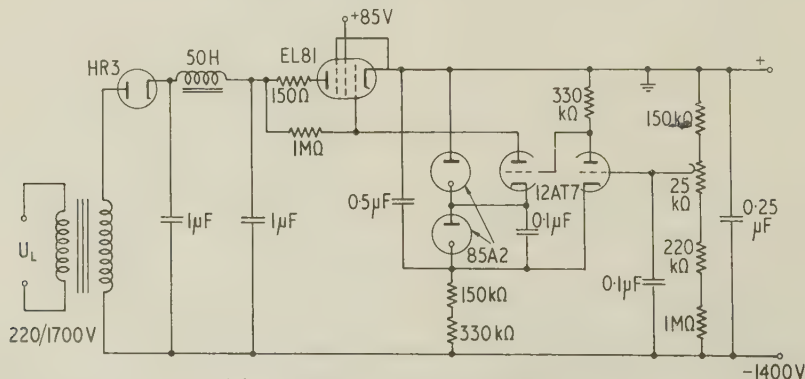


Fig. 6. High voltage power supply.

The sensitivity of the fluorimeter is better than 1 μg of uranium per cake. The total background noise of the instrument without any sample is about a fifth of the blank reading (blank = fused cake of sodium fluoride without any uranium, used for calibration purposes only). The fluorimeter is unaffected by line voltage variations up to $\pm 10\%$, due to the light-stabilizing circuit and the regulated power supplies.

Acknowledgment

This work has been carried out under the auspices of the Ministry of Defence, Israel, and the Division of Electronics and Telecommunication of the Technion, Israel Institute of Technology. Without the aid from both institutes this work could not have been satisfactorily completed.

Appendix

The transductor, its design and performance

A transductor was selected as the power regulating element in preference to thyratrons, high power vacuum tubes, relays or transistors.

A self-saturated reactor was designed as it is much smaller than a non-feedback unit with a similar performance. The feedback ampere turns $n_f i_f$ partially neutralize the core magnetization due to the load $n_a i_a$. The control current i_c supplies only the difference between the load and feedback magnetization forces $n_c i_c = n_a i_a - n_f i_f$. The amount of feedback can be expressed by the feedback ratio $h = n_f/n_a$, $h < 1$. The current gain for infinite permeability is

$$G = \frac{i_a}{i_c} = \frac{n_c}{n_a - n_f}.$$

High permeability alloys with a sharp knee in the magnetic characteristic and low losses are indicated for transductor design. Losses of standard silicon iron are greater than those of materials like Mumetal or Permalloy C, often used for magnetic amplifier cores. Standard 4% silicon iron stampings are nevertheless selected as they are cheap and more readily available than special forms for magnetic amplifiers (toroids or four-legged cores). Good utilization of the EI-13 shape (stacked 45 mm high) is achieved by dividing the load windings in two and fitting them on the outer legs of the core. The control and feedback coils are on the inner leg. Transductor dimensions and coil data were calculated in accordance with standard procedures (Frost-Smith 1958) and are summarized in the following table:

	No. of turns	Wire diameter (mm)	Coil resistance (Ω)
Load winding n_a	2×293	0.8	2×1.5
Feedback winding n_f	250	0.8	2.1
Control winding n_c	6780	0.1	2950

The feedback coil has taps for different feedback ratios of 0.75, 0.85, 0.9 and 1.0, to determine empirically the best ratio for the circuit at hand. The optimum was found to be $h = 0.85$, the ratio on which the design calculations were based. Overall arc and transductor behaviour are indicated by combining the transductor curves and the reversed arc characteristic as shown in Fig. 7. Additional transductor

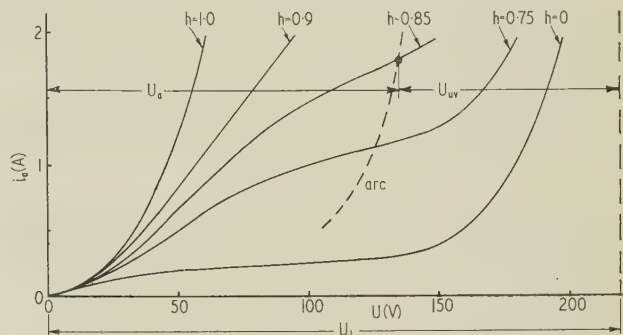


Fig. 7. Transductor and arc characteristics.

The transductor characteristics are shown for a control current of $i_c = 10 \text{ mA}$.

curves for different control currents were used for the detailed evaluation of the circuit. The shapes of the transductor curves vary with the material used and with the residual air gap in the magnetic structure. As the arc and transductor curves are nearly parallel for $h = 1.0$, no stable operation at safe currents is possible. This had, of course, been expected and the coil for $h = 1.0$ was added for test purposes only. On the other hand, no arc could be maintained without feedback, as the current was then limited by the transductor to a value below the minimum value required for a stable arc discharge.

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Differential volumenometer for measuring minute volume changes in solids

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Abstract

The design and use of a differential volumenometer for measuring volume changes of solid samples to ± 5 parts per million are described. The sample, sealed in a reservoir with only a capillary outlet, is covered with mercury, in which it must not be soluble. Any alteration in the sample volume, such as might be produced by heating it while in the volumenometer, is detected as a change in the level of the mercury meniscus in the capillary. Measurements of this level are made while the volumenometer is held at a standard temperature. The volumenometer may be heated to at least 250° C to produce changes in a sample.

During the heating of volumenometers containing metal samples, small amounts of gas have been observed to evolve under the mercury. This affects the measurements, and a procedure is described for removing such gas from the volumenometer. Data on the volume changes occurring during the annealing of cold-worked titanium in stages between 25° and 250° C are presented as an example of the application of this instrument.

1. Introduction

A DIFFERENTIAL volumenometer was developed for measuring with a precision of a few parts per million the volume changes that occur when lattice defects anneal out of a solid. This instrument is a direct descendant of the fluid dilatometer (Reilly and Rae 1953), and in its simplest form consists of two reservoirs connected by a capillary tube (Fig. 1). The lower reservoir E, containing the sample, and part of the capillary D are filled with mercury. Any change in sample volume, for example as a result of heating the lower reservoir and annealing the sample, is measured as a change in the liquid level in the capillary. As is evident, the measurements of liquid level before and after annealing must be made under identical conditions. The equipment and precautions required to insure this are discussed below, and an example of experimental results is given.

2. Description of apparatus

The lower reservoir E (Fig. 1) has a filling tube F, which can be sealed after the sample G is introduced. A capillary D connects this bulb to the upper reservoir B which, in turn, is joined to a vacuum-grade stopcock A. The re-entrant tube C prevents any liquid in the upper reservoir from reaching the stopcock and its grease.

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Since the volume of the lower reservoir and the capillary must be very stable despite heating and cooling, they are made of clear fused quartz, which Moreau, Hall and Leach (1957) have shown in tests of thermometers to possess excellent stability. The remainder of the instrument is of borosilicate glass, joined to the capillary by a graded seal. The capillary

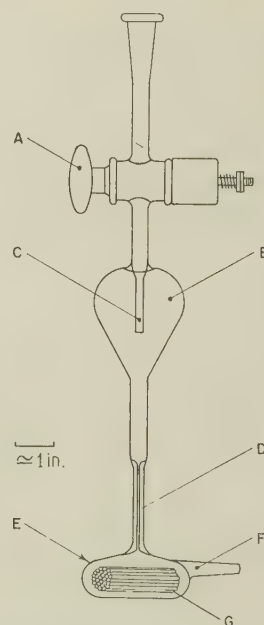


Fig. 1. Design of differential volumenometer.

A, stopcock; B, upper reservoir; C, re-entrant tube; D, capillary; E, sample bulb; F, filling tube; G, sample.

was chosen to have an inside diameter of one millimetre because this size is readily available and gives few problems with sticking of the volumenometer fluid. The lower reservoir has a volume of 25 cm³ and conveniently holds a 10 mm sample. For these quantities a change in sample volume of one part per million (1×10^{-5} cm³) is equivalent to a change of liquid level in the capillary of 12.7 microns.

The liquid used in a volumenometer must fulfil several stringent conditions. These include freedom from decomposition or reaction with the sample at the highest annealing temperature to be used, a low vapour pressure to prevent loss by evaporation and a perfect run-back from the upper reservoir, into which it expands upon heating. No liquid possesses all these qualities for all cases, and mercury is the only one found that met the run-back requirement.

advantages of solubility for many metals and appreciable pressure can be overcome by certain experimental devices and precautions.

Strachan and Harris (1956-7) have reported no detectable solubility (less than 0.001%) at room temperature for the following metals in mercury: Be, Mg, Al, Si, Ca, Ti, Mn, Co, Ge, Nb, Mo, Ba, W and Ir. The major error introduced by partial solution of a sample in mercury is associated with the difference between the atomic volume of the sample material and its partial molar volume in mercury. From data in the *International Critical Tables* it can be calculated that for lead, zinc, and silver volume decreases of one to four parts per million of sample volume would occur upon solution of 0.001% of one of these metals in the amount of mercury contained in the volumenometer. Since the measurements are always made at the same temperature, no error could ever be involved if the equilibrium solubility were always observed. However, non-equilibrium conditions, such as non-wetting of the sample before heating or super-saturation of the mercury on cooling, could introduce appreciable errors for a partially soluble sample.

A Gaertner M342 micrometer slide mounted as a cathetometer was selected to measure the meniscus position. The smallest division on the drum corresponds to 0.01 mm, and a ten-part vernier reads to one micron. Using a telemicroscope with an objective of two-inch working distance, measurements can be reproduced within ± 5 microns. The cathetometer is used on a granite surface-plate, which is levelled so that sliding the cathetometer small distances it will not change the reading by more than one micron. The axis of the cathetometer screw is set vertical and parallel to the volumenometer capillary within 0.5°. This amount of misalignment can produce a maximum error of 0.9 micron in a measurement of the distance from the meniscus to a fiduciary mark.

In a measurement of the height of a mercury meniscus the essential point is to avoid the reflection of light toward the observer from near the top of the domed meniscus (Beattie, Paisdell and Kaye 1941). Such a reflection would make the meniscus appear to be lower than it actually is. The heavily-bulbed capillary presents an additional difficulty since it acts as a strong diverging lens and spreads the light away from the centre of the tube, leaving it dark with little contrast to the shadow of the meniscus. The solution adopted employs a very wide source of diffuse illumination to overcome the divergent effect of the capillary and a movable horizontal plate to prevent illumination of the meniscus top by light inclined downward at more than two degrees to the horizontal. This inclination produces an apparent change in height of less than one micron.

Motion of the meniscus must be measured with reference to a fixed point on the volumenometer, which in this work was a narrow groove across the capillary. The groove was cut by clamping a guide on the capillary at the desired point and dragging a tungsten wire one mil in diameter, on which a small amount of fine diamond dust in a paste vehicle had been applied, lightly but firmly across the capillary several times. The cathetometer cross-hair can be set to touch the edge of such a line very reproducibly within a few microns. The level of the peak of a mercury meniscus varies with its shape. The increase in peak height upon doming from flat shape was found experimentally to be one-third the change in meniscus depth, in good agreement with an approximate analysis. This value was adopted for correcting measurements of meniscus height to a standard meniscus shape.

3. Temperature and pressure effects

Since a filled volumenometer is essentially a large thermometer, its temperature must be carefully controlled during measurements of the height of the liquid meniscus. An apparent volume increase of one millionth of the sample volume will be produced by the expansion of sample and mercury resulting from a temperature rise of 0.003 deg c.

An aquarium-type water bath operating at 25° c and controlled by a large mercury thermoregulator was found satisfactory for holding the temperature of the volumenometer constant during measurement. The thermal fluctuations observed in this bath with a Beckmann thermometer were less than the minimum visible change (± 0.001 deg c) for short periods. However, since the temperature sometimes changed by 0.010 deg c over the course of several days, the bath temperature was recorded at each measurement, and the meniscus height appropriately corrected. The correction was determined experimentally for each volumenometer-specimen combination, although it always agreed within 5% of the values of about 4 mm per deg c calculated from published data.

To prevent any contamination of its contents, each volumenometer is evacuated and filled with one atmosphere of argon at 25° c, and its stopcock closed. As a result, any change in atmospheric pressure causes a slight change in the volume of the lower bulb of the volumenometer. Hence, each measurement of meniscus height is corrected to a standard pressure using an experimentally determined coefficient. Values of about two microns per millimetre of mercury have been found.

4. Experimental technique

The procedures followed in measuring the volume changes occurring during the annealing of a cold-worked metal illustrate the experimental technique. The metal, vacuum annealed in general, may be cold-worked in any of several ways, but precautions, such as precooling and working by easy stages, must be taken to prevent any subsequent annealing. The sample rods are loaded into the carefully cleaned volumenometer, and the filling tube is sealed while the sample is kept cold with solid carbon dioxide. A slow current of dry argon prevents condensation of moisture on the cold sample during sealing.

After connection to a cooled container of mercury and a vacuum system, the volumenometer is pumped for at least a day to a pressure of about 3×10^{-6} mm Hg, as measured on a trapped ion gauge. Mercury is then carefully poured into the volumenometer to fill the lower reservoir and capillary. The volumenometer is opened to the atmosphere, and the excess mercury removed from the upper reservoir and part of the capillary with a slender glass tube. The instrument, held at 25° c, is then evacuated and filled with dried argon to a standard pressure (750 mm Hg). After determination of its temperature and pressure coefficients, the volumenometer is placed in the constant-temperature measurement bath, and the meniscus-to-fiduciary distance is measured.

Ideally, all that is now required is to heat the lower volumenometer bulb to the annealing temperature of interest for the desired time, cool, and replace it in the measurement bath for determination of any change in the meniscus position. The heating is accomplished rapidly in liquid baths, to 60° c in water and to 250° c in Ucon 50-HB-280-X fluid (by Union Carbide Chemicals Company), to minimize uncertainties in the time of annealing. The upper reservoir is cooled with an

air blast during the heating to prevent any appreciable evaporation of mercury.

This procedure worked very well up to about 100° C, with a reproducibility of ± 2 parts per million of sample volume. However, above this temperature small amounts of gas were evolved in the lower bulb, making further measurements meaningless and casting suspicion on the values obtained at somewhat lower temperatures. Vacuum annealing of the metal samples before cold-working did not prevent this formation of gas, which may result from reaction of the sample with moisture adsorbed on it. Several days of evacuation before initially pouring the mercury over the sample were no more effective. Gas chromatography definitely established hydrogen as the gas in one experiment, but the amount was very small. In the experiment with titanium, on which data are presented later, the total volume of gas evolved was $7 \times 10^{-3} \text{ cm}^3$, equivalent to $0.6 \mu\text{g}$ of hydrogen.

5. Removal of evolved gas

To overcome this difficulty a method was devised for removing gas from the lower bulb. It consists of evacuating the volumenometer, pouring the mercury into the upper reservoir, continuing the evacuation to remove the gas from the lower bulb, and finally pouring the mercury back to cover the sample in the lower reservoir. Mercury can be lost during this process by splashing into inaccessible points, sticking in the upper reservoir and evaporation. These losses are minimized by the techniques described below.

If any appreciable amount of splashing occurs droplets generally find their way into the re-entrant tube leading to the stopcock, from which it is difficult to effect their return. To reduce splashing, the junction between the upper reservoir and the tube coming to it from the capillary is very carefully shaped to allow smooth pouring of the liquid. Droplets in the upper reservoir or on the outer wall of the re-entrant tube can be picked up by rotation of the volumenometer to bring them into contact with the main pool of mercury. A Tesla coil can be used to neutralize and permit collection of any charged droplets. Mercury may also stick to any foreign material on the glass, so that scrupulous cleanliness is required.

Evaporation losses can be minimized by reducing the vapour pressure of the mercury or by decreasing the exposed mercury surface. When mercury at -25°C is held in the upper reservoir and exposed to a vacuum for six hours, the loss of mercury is below the limit of experimental error. Similarly, the loss of mercury at room temperature is negligible when only the small area of mercury in the capillary is exposed to a vacuum. Both these methods are used in the procedure adopted as standard and called tipping. The volumenometer is first evacuated for five minutes at room temperature to remove all but a small fraction of the gas from the upper bulb. The stopcock is temporarily closed, and the mercury poured into the upper reservoir. The volumenometer is placed on its side with the upper bulb in a bath at -25°C , and the stopcock is opened to permit evacuation for 25 or 60 minutes. After the pumping period, when a trapped ion gauge normally reads $3 \times 10^{-6} \text{ mm Hg}$, the stopcock is closed, the mercury pool moved about to pick up stray droplets of mercury and the mercury poured back to the lower bulb. A calculation shows that if all the permanent gas in the lower reservoir is trapped when the mercury is repoured, its pressure would have to have been one hundred times the ion-gauge reading to result in a bubble under one atmosphere pressure equal to one millionth of the sample

volume. The volumenometer is again filled with argon at a pressure of 750 mm Hg and placed in the measurement bath for reading the meniscus height.

As a check on reproducibility, the entire tipping procedure and measurement were generally repeated two or three times after each annealing treatment. The results fell within a range of ± 5 parts per million of sample volume in all cases.

6. Experimental results

The annealing of a cold-swaged sample of commercial titanium was followed in this differential volumenometer. Presumably the titanium contained many dislocations and lattice vacancies produced during the deformation. Either defect causes a small increase in sample volume, so decreases in volume are to be expected as these defects disappear.

The data obtained are reproduced in Fig. 2, with the volume change expressed in parts per million of sample volume.

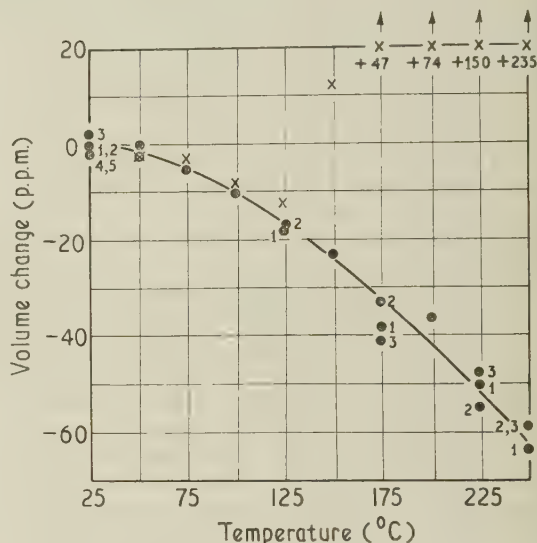


Fig. 2. Volume change of cold-worked titanium after half hour annealing stages at 25 deg c intervals.

× after annealing but before tipping to remove gas. • after tipping; the adjacent number shows the number of tippings.

The observed decrease in volume, totalling about 60 parts per million, far exceeds the experimental errors involved and is attributed to the elimination of lattice defects. The group of points at 25° C, obtained by tipping the instrument several times, falls within the range of ± 2 parts per million typical for reproducibility under these conditions. The points indicating volume change after annealing but before tipping to release evolved gas show clearly that gas formation first became important at 125° C and increased rapidly in amount at higher temperatures. The spread of experimental points became wider, up to ± 5 parts per million, at temperatures for which appreciable gas evolution occurred. The numerals beside the points in Fig. 2 indicate the number of tippings after the latest anneal. They show no systematic change of volume with an increase in the number of tippings after a heat treatment.

Since some mercury is lost from the volumenometer each time it is evacuated, an error is accumulated with the tipping. An estimation of this error from data on evaporation rates gives a total loss equivalent to less than 5 parts per million of sample volume for the entire experiment with titanium.

The evolution of gas from the surface or interior of a sample might, depending upon its source, also cause a change in sample volume. However, this change would be negligible for the small amount of gas, equivalent to $0.6 \mu\text{g}$ of hydrogen, and in the experiment on titanium. If this much hydrogen had been adsorbed on the sample surface with a density equal to that of liquid hydrogen, its removal would have caused a volume decrease of one part per million of sample volume. Had the hydrogen been in internal pores, no volume change would have occurred. If this hydrogen had been in solid solution in the sample, a fractional volume change equal to $3\Delta\alpha/\alpha$ would have occurred, where $\Delta\alpha/\alpha$ is the fractional increase in lattice parameter produced by the amount of hydrogen in solution. For most metals and for the very small amount of hydrogen involved, $\Delta\alpha/\alpha$ will be below 10^{-6} , so that this volume change is negligible. For titanium, McQuillan (1950) reports no change in lattice parameter upon the solution of hydrogen.

7. Volumenometer applications

Evidently the annealing of a quenched or irradiated sample could be done in the same way, and volume changes occurring as a result of precipitation or order-disorder reactions in a sample could be handled similarly. Possibly the transformations from metastable to stable precipitate structures could be detected as discontinuities in the curve or in the slope of the volume-time curve (at a constant temperature). The temperature range over which the differential volumenometer is applicable can be broadened somewhat by changes in the auxiliary equipment. Annealing temperatures as high as up to the boiling point of mercury (357°C) should be feasible using a suitable bath like molten tin or solder. If volume changes occurring below 25°C are of interest, the temperature of the measurement bath could be decreased nearly to the freezing point of mercury (-39°C). All manipulations would then be done at temperatures below those at which the change to be studied occurs.

8. Summary

A new instrument, the differential volumenometer, and a procedure for its use to measure small volume changes in a

sample as a result of heat treatment at temperatures from 25 to 250°C have been described. A volume change can be measured as a variation in the level of mercury in a capillary tube coming from an otherwise closed reservoir filled with the sample and mercury. Fused quartz is used for the reservoir and capillary to provide minimum volume hysteresis after heating and cooling. Standards of temperature, atmospheric pressure and meniscus shape are chosen, and corrections are made for any deviations from these at the time of measurement.

Small amounts of gas were generated in the specimen reservoir when heating metal samples therein to 100°C or above, perhaps by reaction of the sample with water adsorbed on it. The volumenometer is designed so that the mercury can be poured away from the sample, allowing removal of any evolved gas by evacuation, and then poured back without a measurable loss. The changes of volume during the annealing of a cold-worked titanium sample are presented to show a reproducibility of ± 5 parts per million of sample volume.

Acknowledgments

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Phase and modulation fluorometer

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Abstract

The instrument, which is designed for the measurement of fluorescence decay times of 10^{-7} – 10^{-9} s, comprises a 10 Mc/s hydrogen discharge lamp, fast photomultiplier, variable delay line and detector circuit for phase and modulation analysis of light signals from the lamp and specimen. Studies have been made of the transit time variations in 56 AVP and 6810 A photomultipliers, and preliminary measurements have been made of the fluorescence decay time of quinine sulphate solutions.

1. Introduction

THE phase fluorometer is an instrument designed primarily for the measurement of fluorescence decay times. A periodically modulated light source is used for the optical excitation of the specimen, and the phase of the excited light emission is compared with that of the exciting light. If the decay of the emission is exponential of decay time t_f , then its phase relative to that of the exciting light is

$$\phi = \tan^{-1}(\omega t_f) \quad (1)$$

where ω is the angular frequency of the modulation (Birks and Little 1953, Bailey and Rollefson 1953).

Alternatively ϕ and hence t_f can be obtained from a comparison of the degrees of modulation. If the degree of modulation of the exciting light is m_s , then that of the excited emission is m_f , given by

$$m_f = m_s \cos \phi. \quad (2)$$

The several alternative forms of phase and modulation fluorometers described by previous writers differ in the methods used for (i) modulating the light source, and (ii) measuring the phase change or degree of demodulation.

The commonest type of modulator employs an ultrasonic standing-wave diffraction grating, formed usually by a liquid cell driven by a quartz crystal transducer, which modulates the amplitude of the light from a steady intense source (Bailey and Rollefson 1953, Schmitten 1953, Scharmann 1956, Venetta 1959). A simpler method was introduced by Birks and Little (1953), who used a high-frequency air discharge tube, operated at about 5 cm Hg pressure and driven directly by a 7.5 Mc/s oscillator. A similar light source was used by Hamilton (1957).

Several types of phase analyser have been described. In some instruments (Maerks 1938, Tumermann and Szymanowski 1937, Galanin 1948, Scharmann 1956) a variable light path is employed. More usually a known delay, provided by an RC phase-changing circuit (Bailey and Rollefson 1953, Venetta 1959), an artificial delay line (Birks and Little 1953) or different lengths of cable (Liebson 1952), is introduced between the signals from the source and from the specimen,

which are fed into a mixing circuit which records a particular fixed phase relationship between them. Liebson (1952) fed the signals through 10 Mc/s amplifiers to horizontal and vertical plates of an oscilloscope, and adjusted the delay to degenerate the Lissajous patterns to a 45° line. Bailey and Rollefson (1953) used a radio receiver with a balanced input which effectively subtracted the two signals, the minimum output occurring when the signals were in phase. Birks and Little (1953) used the photomultiplier detector of the specimen emission as a mixer, its sensitivity being modulated by a signal applied to the first dynode and derived directly from the oscillator via a frequency doubler, variable delay line and constant output amplifier. In the instrument developed by Schmitten (1953), the frequency of the reference signal was increased by 50 c/s, mixed with that from the photomultiplier observing the emission, and the phase of the 50 c/s heterodyne signal was measured directly with a cathode-ray tube. The phase detector used by Venetta (1959) employed two diodes in a balanced system which gave zero output when the two signals were 90° out of phase. Other earlier types of phase fluorometer have been reviewed by Bonch-Bruevich (1956).

Modulation analysis has only been used by a few observers. Birks and Little (1953) measured the photomultiplier current as a function of the phase of the signal modulating the emission, and hence obtained the modulation of the incident light. Hamilton (1957) measured the d.c. and a.c. components of the photomultiplier current and thus determined the degree of modulation.

2. The phase and modulation fluorometer

The present instrument is designed to be simple to set up and operate, yet to possess the accuracy of more elaborate systems. It is suitable for the measurement of changes in phase and in modulation, so that two independent measurements of ϕ and t_f can be made, thus providing an internal check on consistency from Eqns (1) and (2).

A 10 Mc/s modulated hydrogen discharge lamp is used as the reference signal being derived directly from the lamp current. A fast photomultiplier, a commercial variable delay line and a phase-detector circuit based on that of Venetta (1959) are employed for the phase and modulation measurements.

2.1. The modulated light source

Malmberg (1957) has shown that if a fast current pulse is passed through hydrogen at about 10 cm Hg pressure, the resulting light flash is also very fast, with a decay time of the order of 1 ns. This result has been verified by a colleague, I. H. Munro, using a Philips 56 AVP photomultiplier and a pulse-sampling oscilloscope for direct observation of the light flashes. It was decided therefore

a hydrogen lamp of the type described by Malmberg, [1] to modulate the current through the lamp at a frequency 10 Mc/s, since the fast decay time of the emission should provide a high degree of modulation.*

The lamp-driving circuit, shown in Fig. 1, is found to give controllable stable output. The control circuit, which is

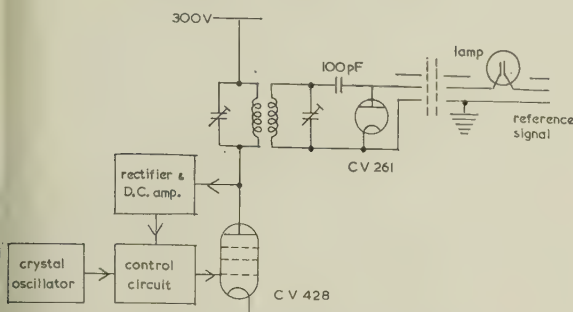


Fig. 1. The lamp driving circuit.

anged to stabilize the a.c. voltage at the anode, is derived m a stabilized r.f. e.h.t. power pack and is not shown in ail. The secondary of the tuned transformer is con- ducted to have as high an impedance as possible, limited the stray capacities and circuit losses. The diode and ndenser act as a d.c. restoring circuit, which prevents quency-doubling of the light signal, and which also

2.3. The phase and amplitude analyser

The relative phase and amplitude of I_a are measured by a balanced phase-sensitive detector, operating at the fundamental 10 Mc/s frequency. The circuit is shown in Fig. 2. I_a is amplified by the tuned 10 Mc/s amplifier V_1 and fed inductively to the secondary of the transformer T. The reference signal, derived from the current through the lamp, is taken via the variable delay line to the 10 Mc/s tuned amplifier V_3 , and the output is fed to the centre tap of the secondary of T.

If the voltages due to the photomultiplier and reference signals are S_1 and S_2 respectively, the voltages at the ends of the secondary of T are $S_2 + \frac{1}{2}S_1$ and $S_2 - \frac{1}{2}S_1$. These are rectified by two identical circuits employing the double diode V_2 , and the difference between the rectified voltages is recorded on a sensitive galvanometer connected between O and O. The balance control A and zero control B are adjusted to allow for any difference in the characteristics of the two diodes. A is set so that small changes in the reference level cause no change in output, when no signal is present. B is then adjusted to cancel out any residual current.

The galvanometer current G is proportional to

$$|\mathbf{S}_2 + \frac{1}{2}\mathbf{S}_1| = |\mathbf{S}_2 - \frac{1}{2}\mathbf{S}_1|,$$

as represented in the vector diagram (Fig. 3). $|\mathbf{S}_2|$ is chosen to be much greater than $|\mathbf{S}_1|$, so that G is proportional to $|\mathbf{S}_1| \cos \theta$, where θ is the phase difference between $\mathbf{S}_1$ and $\mathbf{S}_2$. As θ is varied by altering the variable delay, G oscillates

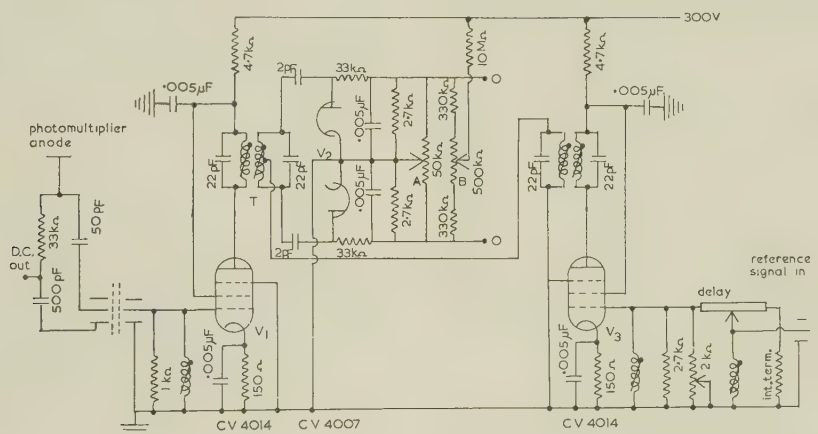


Fig. 2. Photomultiplier output and the phase and amplitude analyser circuit.

cludes the peak voltage in the period before the discharge lamp strikes, thus facilitating its ignition. The lamp must be connected to earth through a relatively low impedance, and the reference signal is conveniently taken at this point which forms the input of the variable delay line (Cossor type 1048).

2.2. The photomultiplier output circuit

A fast high-gain photomultiplier is used for the light detection. The d.c. component I_d and the a.c. component of the photomultiplier output current are separated by the circuit shown to the left of Fig. 2, I_d being measured by a galvanometer and I_a being fed to the analyser circuit.

* A hydrogen pressure of about 4 cm Hg is found most satisfactory for this purpose, since it gives greater light output and stability of discharge with appreciable loss in modulation depth, and also a lower striking voltage.

sinusoidally about zero, with an amplitude proportional to $|\mathbf{S}_1|$ and I_a , and independent of $|\mathbf{S}_2|$ and of any noise components in the signal, which being random in phase give a zero mean output.

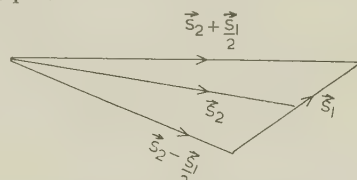


Fig. 3. Vector diagram representing the signal voltages on the secondary of the transformer T.

2.4. Phase and modulation measurements

Measurements of the phase change ϕ (and hence of t_f) involve a comparison of the photomultiplier signals produced

by the light source alone and by the illuminated specimen (with appropriate filters for separating the incident and excited light). Two methods have been used to measure ϕ .

(i) When $G = 0$, $\theta = 90^\circ$, and this balance position provides a sensitive phase reference point. The change in the delay line required to restore balance in changing from one photomultiplier signal to another gives a direct measure of the phase difference ϕ between them.

(ii) The delay is initially adjusted to give balance, $G = 0$, with the first signal. The current G with the second signal is now observed, and the delay is then adjusted to give maximum current $G_{\max}$. The phase difference between the two signals is given by

$$\sin \phi = G/G_{\max} \quad (3)$$

The second method has the advantage that it is independent of the delay line calibration, which might be disturbed by slight mismatching. However, no difference has been found in the measurements of ϕ made by each method.

Measurement of the relative degree of modulation of m_f/m_s of the excited light compared with the exciting light provides an independent method of determining ϕ from Eqn (2). Since the degree of modulation

$$m = I_a/I_d \quad (4)$$

m_f/m_s is obtained from the relative magnitudes of the d.c. components I_d and a.c. components $G_{\max}$ in the two cases. The determination of ϕ from the observed demodulation provides a useful check on the direct phase measurements. Any inconsistency may be considered symptomatic of a non-exponential decay, or of some inherent error.

2.5. Tests on light source

Measurements have been made of the uniformity of the phase and modulation depth of the light from the discharge lamp. A small section of the cone of light from the lamp was selected by a small movable aperture and scattered uniformly over the multiplier photocathode by a diffuse plate. Small variations in phase and modulation depth, just within the limits of measurements (~ 0.1 ns and 2% respectively) were observed. Hence in making subsequent comparative measurements, care was taken to maintain a constant optical geometry.

3. Photomultiplier transit time measurements

Measurements have been made of the variations in transit time and relative response across the photocathode of two fast photomultipliers considered for use in the instrument. These are the Philips 56 AVP and the R.C.A. 6810 A tubes. The optical arrangement is shown in Fig. 4. The diffusing plates are a pair of Perspex disks ground on both sides with carborundum powder. The mask covering the photomultiplier window has 2 mm diameter holes at different distances from the centre, all but the appropriate one of these being covered with opaque tape during the measurements. The transit time differences between different points on the cathode were determined directly from the corresponding phase differences.

Typical measurements on the two tubes are plotted in Figs 5 and 6. Measurements of the small delays involved were reproducible to within 0.1 ns, this being the standard deviation obtained on a series of measurements between the same two points on the photocathode. Since only one determination was made of most of the points on the graphs this represents the estimated probable error.

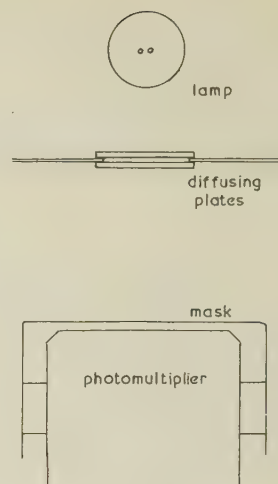


Fig. 4. Optical arrangement for measurement of transit time variations. Mask has 2 mm diameter holes at various distances from centre, all but one being closed.

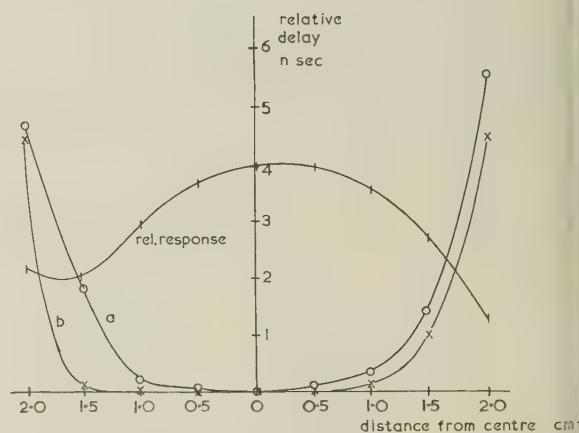


Fig. 5. RCA 6810 A photomultiplier. Transit time variation along diameter: *a*, focusing electrode adjusted for maximum output with uniform illumination; *b*, focusing electrode dynode 1 potential (142 v).

Relative response per unit area same for *a* and *b*.

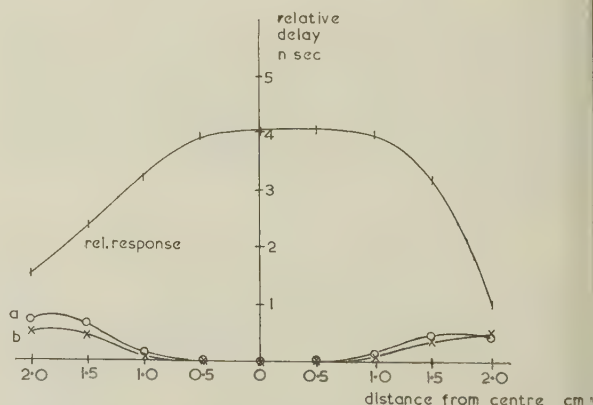


Fig. 6. Philips 56 AVP photomultiplier. Transit time variations along diameter. Dynode 1 potential: *a*, 323 v; *b*, 535 v. Relative response per unit area same for *a* and *b*.

The 6810 A tube was operated at 1.7 kv from the potential divider recommended by the manufacturers. With the focusing electrode adjusted for maximum overall gain, the results were as shown in Fig. 5, curve *a*. Operation of the focusing electrode and dynode 1 at the same potential reduced somewhat the transit time variation (Fig. 5, curve *b*), but also resulted in a considerable reduction in gain.

Figure 6, curves *a* and *b*, show the results obtained for the 56 AVP tube, operated at an overall potential of 2 kv, with the focusing and deflecting electrodes adjusted to give maximum response to uniform illumination, and with dynode 1 at 323 v and 535 v for *a* and *b* respectively, relative to the photocathode. The electron transit times and their differences from cathode to dynode 1 should, neglecting the initial photoelectron velocities, be inversely proportional to the square root of the inter-electrode potential.

The mean value of the ratio of the transit time differences in cases *a* and *b* was found to be 1.27 ± 0.06 , which may be compared with the ratio of the values of $V_1^{-1/2} = 1.29$, indicating that the transit time differences arise during the transit from the photocathode to dynode 1. The 56 AVP and 6810 A tubes are both suitable for use in the fluorometer.

4. Fluorescence decay time measurements

As a test of the operation of the instrument, measurements have been made of the fluorescence decay time of a 10^{-5} M solution of quinine sulphate in 10^{-2} N HNO_3 . The salt was a standard specimen, supplied by W. S. Metcalf of University of Canterbury, Christchurch, New Zealand, to different laboratories for comparison purposes. The preliminary results give values of $t_f = 20.3 \pm 0.6$ ns from the phase measurements, and of $t_f = 21.2 \pm 0.4$ ns from the demodu-

lation measurements. The slight discrepancy is being investigated. These values may be compared with those of 20.5 ns observed by Metcalf, and of 22.8 and 25.2 ns observed by Schmillen, on solutions prepared from similar specimens (Metcalf, private communication 1960).

The fluorometer is being used in conjunction with an alternative instrument (Birks and Munro, to be published), which uses a pulsed light source and pulse-sampling oscilloscope, for the study of the photofluorescence decay times of organic compounds.

Acknowledgment

One of us (D. J. D.) wishes to acknowledge the tenure of a D.S.I.R. research studentship.

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Improved attachment for high temperature single-crystal X-ray work

by A. BARCLAY, A.I.S.T., and J. D. DONALDSON, B.Sc., Ph.D., Aberdeen University, Chemistry Department, Old Aberdeen

MS. received 1st February 1961

Abstract

This attachment to an x-ray goniometer permits single-crystal or powder photographs to be taken using copper radiation up to 900°C. The alignment of the heating element can be checked and altered while the attachment is in use, and the apparatus does not have to be cooled before each film is developed.

THE apparatus described was designed to overcome two disadvantages in the use of a previous attachment (Dent and Taylor 1956). The disadvantages (Dent 1957) were (i) that it was difficult to align the crystal in the x-ray beam because of the rigidity of the apparatus, (ii) that the sample had to be cooled to room temperature before the film could be developed. The improved attachment described is for a Unicam S25 type goniometer with an 11.46 cm semi-circular cassette, and is suitable for single-crystal and powder work, with copper radiation, up to 900°C.

Description

The apparatus (Fig. 1) consists of two parts: the heating element with its support, and a framework to attach this to the goniometer.

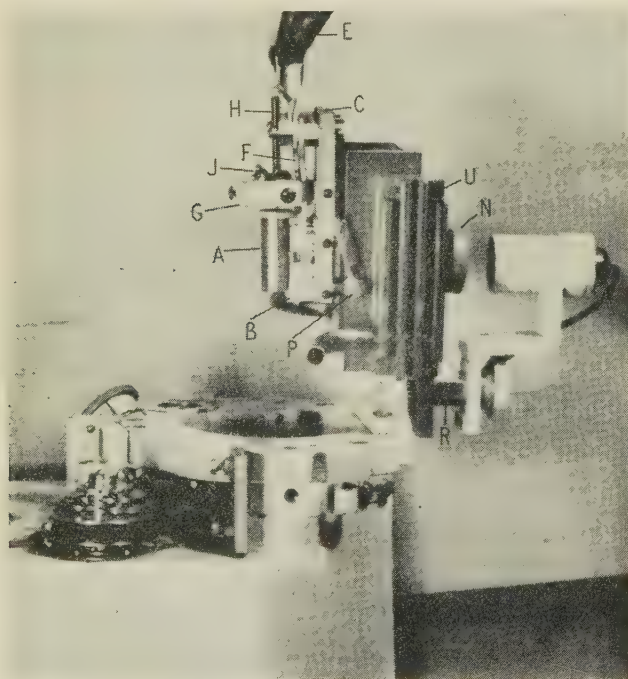


Fig. 1. General view of camera and attachment.

Heating element and support

The heating element A consists of a cylinder (diameter 1 cm, height 3.6 cm) of 0.025 mm nickel foil, which also serves as a filter (Dent and Taylor 1956, Stewart 1949) for Cu K β radiation. It is supported by two right-angled, silver-plated copper supports B (position shown in Fig. 2), which are shaped as shown to prevent

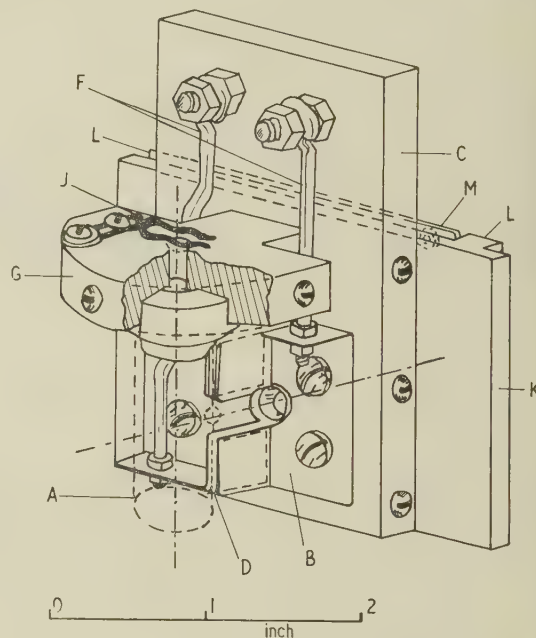


Fig. 2. Heating element and support.

fouling of the x-ray beam. The supports are attached to a Sindanyo* block C and are kept 4 mm apart by asbestos sheet D. The heating element is formed from a strip of nickel foil (9.5 cm $\times$ 3.3 cm $\times$ 0.0025 cm), 3.2 cm of which on each side being folded under the angle-pieces to support the heating cylinder and also to carry the current to the element A. Slits are cut out of the supporting nickel foil opposite the collimator to prevent fouling of the x-ray beam and holes are punched in the foil to allow the screws attaching the angle-pieces to the block C to pass through. A 1 mm hole is cut in the heating element in line with the collimator to allow the direct x-ray beam to pass through. The junction of nickel foil with Sindanyo are insulated with asbestos tape. The current is fed through two heavy leads E, connected to the angle-pieces B by two silver-plated leads F and then to the heating element by the supporting nickel foil.

* Turner Asbestos Co. Ltd.

the leads F is connected to the top of one of the angles and the other lead to the bottom of the second angle (as shown in Fig. 2).

Sindanyo cap G holds the top of the heating element in position and also serves as a support for a twin-bore silica tube H carrying a chromel-alumel thermocouple. The thermocouple is held in position by a spring clip J, so that the thermocouple is located 1 mm above the sample. The base and cap G are fitted with screws, as shown in Figs 1 and 2, and a heat radiation filter of 0.012 mm aluminium foil, which completely surrounds the element while the attachment is in use. The high-temperature element on base C is welded to a brass plate K ($2\frac{1}{4}$ in. $\times$ $1\frac{7}{8}$ in. $\times$ $\frac{1}{4}$ in.) which has a slot L machined to fit a $\frac{1}{8}$ in. sliding groove. A polished reflector M is fitted to the back of plate K and an air gap is left between the plate and the reflector to reduce the loss of heat. Parts C, K and M have a $\frac{5}{8}$ in. hole in a suitable position to allow the collimator N to pass through.

The element is fed through a transformer of maximum current 60 A at 4 v, which is connected to the mains through a variac preceded by a constant voltage transformer.

Attachment to goniometer (Fig. 3)

The high-temperature device slides into position on the goniometer by means of the $\frac{1}{8}$ in. grooved slides O and is

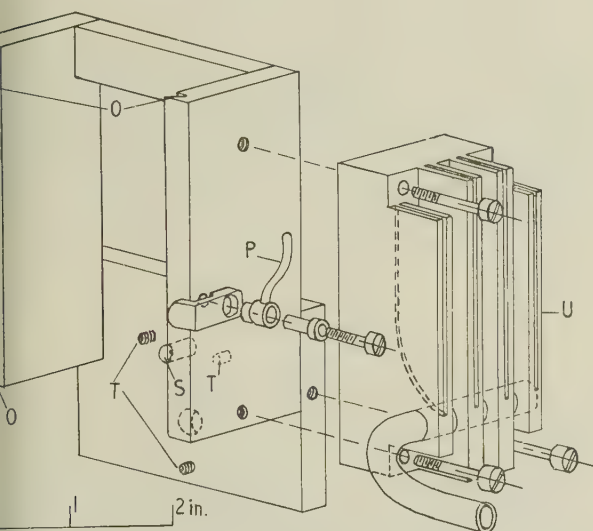


Fig. 3. Framework for attachment of heating element and support to the goniometer.

is held in position by a locking key P. The attachment is made from $\frac{1}{4}$ in. thick brass and is fitted to the goniometer by means of a special screw R on the collimator-light screw hole. The screw R contains a concentric threaded screw hole so that the collimator light can be used. A locating pin S fits into a hole bored in the collimator support of the goniometer and fixes the position of the attachment. Three Allen screws provide a certain amount of adjustment of the position of the attachment and are used to align the furnace before making photographs. Air-cooling pipes U are built on to the sides of the attachment to prevent overheating of the goniometer. All screws in this part of the apparatus are silver-soldered for strength and all brass parts blackened to reduce the loss of heat from the main structure.

Figure 4 is a simplified diagram of the plan and elevation of the apparatus and shows the position of the heating

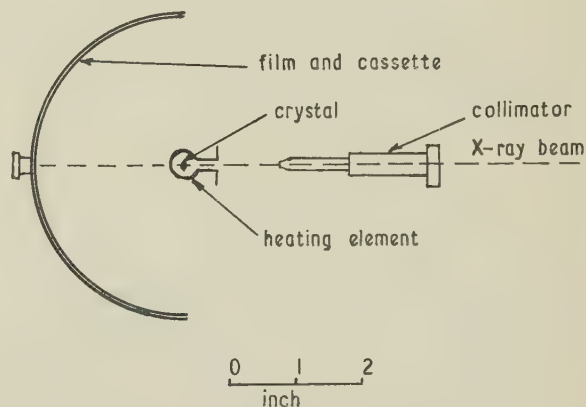
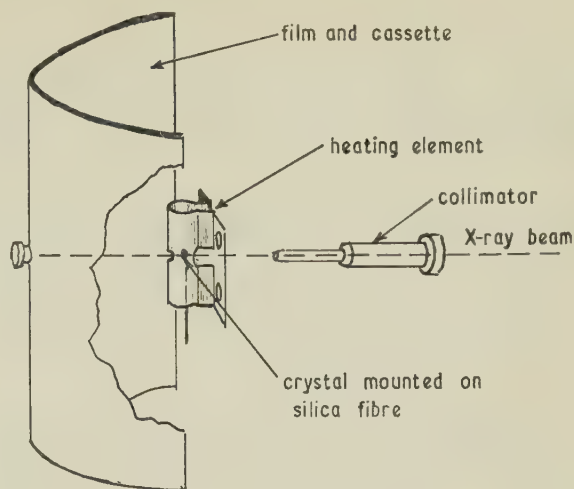


Fig. 4. Plan and elevation showing position of essential features of the apparatus.

element relative to the specimen, the x-ray beam and the film.

Use and performance

The crystal to be studied can be set about a suitable axis and then the high temperature attachment slid into position. Adjustment of the position of the heating element can be made, by means of the Allen screws, at any time during a series of experiments without cooling the apparatus. Use of a semicircular cassette permits development of a film without cooling the crystal to room temperature. For temperature above 400°C the cassette is also cooled by jets of air.

The attachment has been used successfully in the study of a number of thermal transitions in which orientation is retained. Results of these studies will be published in detail later.

Acknowledgment

We wish to thank Dr. H. F. W. Taylor for his helpful advice.

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Fixed attenuators consisting of a network of identical resistors

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MS. received 21st February 1961

Abstract

Fixed attenuators constructed of identical resistors have advantages of freedom from distortion by the stray self-inductance of the resistors and freedom from the effects of ambient temperature changes. A suitable form for such attenuating networks is described. It is possible to design a network of this form to give attenuation in any ratio N to 1, where N is an integer. The minimum number of resistors needed for any value of N is not excessive, being less than seven resistors per decade of N . A table is given which makes the calculation of an optimum network very easy for any value of N up to 400.

IN a recent investigation, a resistance attenuator was required to divide a pulse voltage precisely in the ratio of 101 : 1. It was decided that a network of identical precision resistors should be used, to avoid any error due to the self-inductance of the resistors (see Appendix I) and to avoid changes in the attenuation ratio with ambient temperature (see Appendix II). It was possible to use a sufficiently low resistance R to avoid serious error due to the loading by the stray capacitances, and the impedance of the external load to be applied to the attenuator was high. The power dissipated in the attenuator itself was negligible and it was enclosed in a metal box, which provided electrostatic shielding and also kept all the resistors at the same temperature. The impedance of the source of pulses was low and the attenuator could be left attached to it as a load, when the unattenuated output was being taken, to avoid a change in the output voltage. It was also decided that the attenuating network should be of the simple ladder form, with each series arm consisting of one or more of the equal resistors in series and each parallel arm consisting of one or more of them in parallel. For economy, it was of interest to find the minimum number of resistors which could be used to construct such a network. A general method was found for obtaining all such networks dividing in any ratio $N : 1$, where N is an integer, as follows.

Let the r th stage from the output terminal of an attenuator of the type considered consist of P_r resistors in the parallel arm and S_r resistors in the series arm (see Fig. 1). Let the conductance presented to it by the preceding stages be

B_{r-1}/RA_{r-1} , where A_{r-1} and B_{r-1} are integers prime to each other. This conductance is increased by the parallel arm P_r to B_r/RA_{r-1} , where

$$B_r = B_{r-1} + P_r A_{r-1}.$$

It follows that B_r is prime to A_{r-1} and also (unless B_{r-1} and $P_r = 1$) that $B_r > A_{r-1}$. The resulting resistance RA_{r-1}/B_r is increased by the series arm S_r to RA_r/B_r , where

$$A_r = A_{r-1} + S_r B_r.$$

It follows that A_r is prime to B_r and also that $A_r > B_r$.

Now B_0 must be taken as zero, to represent the admittance of the external load. If A_0 is taken as 1, values of A_1 and B_1 are obtained which are in accordance with the above equations and such that A_1 is prime to B_1 . Hence it follows by induction that for any network of the type considered of n stages, the corresponding n pairs of numbers A_r and B_r can be derived, obeying the relationships given above. Now the attenuation introduced by r th stage is given by

$$\frac{A_{r-1}/B_r}{S_r + A_{r-1}/B_r} = \frac{A_{r-1}}{A_r}$$

for all stages, including the first, for which $A_{r-1} = A_0 = 1$. It follows that the overall attenuation factor is $1/A_n$, is, that $A_n = N$.

Equations (1) and (2), together with the inequalities $A_{r-1} > B_{r-1}$ and $B_r > A_{r-1}$, respectively, show that the numbers $A_n, B_n, A_{n-1}, B_{n-1}, \dots, A_r, B_r, A_{r-1}, \dots, A_2, B_2, A_1, B_1, A_0 (= 1), B_0 (= 0)$ form a sequence in which each number is the remainder when the preceding number but one is divided by the immediately preceding number. The quotients and corresponding values of S_r and P_r . Now such a sequence of numbers can be generated (as in the ordinary arithmetical process of finding the highest common denominator), starting with any integers A_n and B_n . If the required value of N is taken for A_n and if any number prime to this is taken for B_n , the sequence of quotients will specify a network of desired attenuation factor. There are as many such networks as there are numbers less than N and prime to it, and networks of the type considered are given by this procedure. Table 1 shows two examples for the case of $N = 101$. The method used is such that it is easy to programme a digital computer to find the networks with the minimum number of resistors for a given value of N .

The value of n (3 and 4, respectively, in these examples) is not known, of course, until the procedure is completed in each case. If it is not known in advance whether the

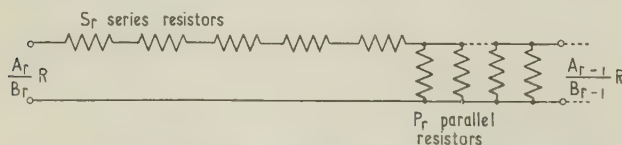


Fig. 1. The attenuation factor introduced by this stage is A_{r-1}/A_r .

e 1. Examples of the calculation for a network with an attenuation ratio of $N : 1$

$N = A_3$	101		$N = A_4$	101	
B_3	39	2	B_4	64	1
A_2	23	1	A_3	37	1
B_2	16	1	B_3	27	1
A_1	7	2	A_2	10	2
B_1	2	3	B_2	7	1
A_0	1	2	A_1	3	2
			B_1	1	2
			A_0	1	1
	11				
					11

n chosen is prime to N , as required, this will be revealed by the procedure. Note that in cases such as the second one, $M = 64$, where the remainder after an even number of divisions is 1, the procedure is modified slightly at the end. The preceding remainder is X , the next quotient is taken $X - 1$, instead of X , giving a final quotient of 1 and

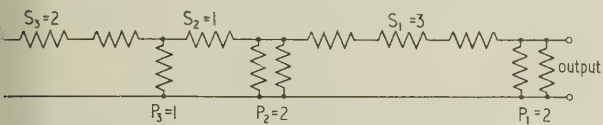


Fig. 2. An attenuator for division by 101 ($B_n = 39$).

making the total number of quotients even. This corresponds to the case $B_1 = A_0 = 1$, when $P_1 = 1$, since $B_0 = 0$. Examples 2 and 3 have been drawn from these examples. The procedure of this method reveals that there are eight networks of seven resistors giving $N = 101$, but none of fewer resistors.

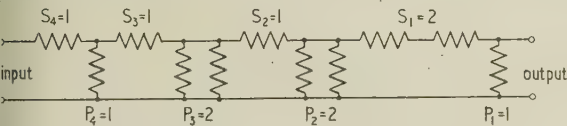


Fig. 3. Another attenuator for division by 101 ($B_n = 64$).

The eight corresponding values of B_n are 30, 37, 39, 44, 57, 64 and 71. The value of 101 was chosen in this particular case as it greatly simplifies the arithmetic when measurements, with and without the attenuation, are made to eliminate or minimize a small zero error in an otherwise very precise measuring device (Vincent and King 1960).

Table 2 shows some additional results for various values of N which were obtained with a digital computer. When the results were calculated, it was observed that no arm of any of the 52 networks containing the minimum number of resistors consisted of more than three resistors. This is in accordance with the fact that the attenuation ratio introduced by any stage exceeds, but in general approximates to, $+1$. The expression

$$\frac{20 \log_{10} (SP + 1)}{S + P}$$

is the minimum attenuation which will be obtained from a stage with arms specified by S and P , in decibels per resistor. When this is tabulated for various values of S and P , it will be found to have a maximum of 3.50 at $S = 2$, $P = 2$ and to increase steadily with increasing values of S and P for other values. It is therefore to be expected that values of

Table 2. Examples of networks with various attenuation ratios, using the minimum number of resistors in each case

N	100	101	1000	1001	10000	10001
Resistors needed	11	11	16	16	21	21
Networks available	8	8	4	12	12	8
Lowest usable B_n	27	30	297	269	3799	2953
Stages with this B_n	3	3	5	5	7	7

S and P of 1, 2 and 3 will be common in the optimum networks. The minimum value of the above minimum attenuation which is found within this range of S and P is 3.01. If it is assumed that arms containing four or more resistors are rare in all the larger optimum networks, it follows that such networks will give more than 20 decibels of attenuation for every seven resistors. The number of resistors required is therefore less than $7 \log_{10} N$, with a solitary exception at $N = 6$ (for which the minimum number of resistors is six, while $7 \log_{10} 6 = 5.45$).

Table 3, which was also calculated by means of a digital

Table 3. The lowest value of B_n to give an optimum network for each value of N

N (tens)	0	1	2	3	4	5	6	7	8	9
	(units)									
0	—	—	—	2	3	2	5	2	3	2
1	3	3	5	5	3	4	7	5	5	7
2	9	8	5	5	7	7	7	8	5	8
3	11	12	7	7	13	8	11	8	7	14
4	11	11	11	12	13	19	17	13	11	18
5	19	11	11	12	17	21	15	13	17	18
6	13	17	23	17	19	18	25	18	19	19
7	29	21	19	27	31	29	21	18	17	29
8	31	31	23	18	19	18	25	19	19	34
9	17	25	21	25	39	29	29	21	27	29
10	27	30	19	37	29	29	31	41	29	30
11	23	31	31	21	25	34	45	43	21	44
12	43	46	33	34	29	27	55	27	47	49
13	47	50	35	29	29	41	31	29	37	30
14	37	41	31	31	55	44	41	41	41	34
15	59	56	41	41	43	46	29	34	57	44
16	43	45	29	44	43	46	49	46	71	50
17	47	50	63	64	31	47	65	49	49	50
18	41	50	41	67	43	68	55	71	69	40
19	41	74	71	81	75	59	75	43	53	55
20	53	46	59	43	55	61	45	76	79	80
21	59	46	81	46	49	49	41	47	59	50
22	93	50	47	66	47	62	49	49	41	50
23	83	50	85	89	71	63	65	64	87	66
24	71	55	65	71	45	88	73	68	91	76
25	67	70	55	68	55	92	75	69	71	100
26	57	100	59	71	101	73	79	79	99	75
27	97	75	103	100	81	76	49	81	63	50
28	107	109	109	76	105	79	79	79	119	80
29	81	68	111	81	67	108	55	109	63	116
30	89	89	111	116	85	112	65	119	117	55
31	71	115	131	119	71	68	69	121	113	73
32	93	68	89	89	89	71	69	74	71	71
33	89	75	89	76	71	123	127	128	129	74
34	101	95	101	131	75	79	75	92	103	98
35	83	76	97	97	127	81	105	109	81	76
36	101	100	97	98	111	79	79	97	107	80
37	133	81	109	100	81	103	105	144	139	105
38	137	107	137	106	67	69	101	104	147	105
39	89	105	149	106	117	142	109	116	111	71
40	117	111	157	108	153	157	109	112	155	121

computer, shows the lowest value of B_n in each case which leads to an optimum network for the value of N . Since the lowest value of B_n is taken, this gives the highest value of S_n and of the attenuator input impedance for an optimum network. For this reason, a number of initial series arms of four or five resistors will be found, when the networks are developed from the values of B_n given. Such an arm is, however, the only arm of more than three resistors in the network, in almost every case, and the generalization remains valid that arms of more than three resistors are rare, when the arms are selected at random from optimum networks. The table includes all values of N up to 400 and enables the corresponding optimum networks to be derived very easily. The number of resistors needed for this range of N will not exceed fifteen. The author has computed the continuation of this table up to $N = 1000$.

Appendix I

The network concerned is composed entirely of identical resistors, each with the same resistance R and self-inductance L . Wiring and mutual inductances and capacity effects can be kept to negligible proportions. It follows that at any frequency f the impedance Z between any two points of the network is of the form

$$Z = \theta(R + j2\pi fL) \quad (4)$$

where θ is a positive real number. If two such impedances

perform a voltage division, Z_1 being the series impedance and Z_2 the load impedance, the division ratio is given

$$\begin{aligned} \left| \frac{Z_1 + Z_2}{Z_2} \right| &= \frac{\theta_1 + \theta_2}{\theta_2} \\ &= \frac{\theta_1 R + \theta_2 R}{\theta_2 R} \end{aligned}$$

where $\theta_1 R$ and $\theta_2 R$ are the corresponding resistances calculated in direct-current theory. Since this ratio is the same for all frequencies, there is no distortion of a signal which is attenuated in the same ratio as direct current.

Appendix II

The network concerned is composed entirely of identical resistors, each with the same temperature coefficient of resistance α and maintained at the same ambient temperature T . It follows that the effect of an ambient temperature change is to alter the value of the resistance R in accordance with the relationship

$$R(T) = R(0)(1 + \alpha T).$$

This does not alter the attenuation ratio.

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VINCENT, C. H., and KING, W. G., 1960, *Nuclear Instruments*, **6**, 57.

A method for gauge factor determination

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S. received 24th November 1960, in revised form 10th March 1961

Abstract

A simple device for the determination of gauge factor of electrical resistance strain gauges is described.

1. Introduction

THE gauge factor of electrical resistance strain gauges is determined by observing the fractional change in resistance of a gauge when subjected to strain. Usually it is required that the gauge factor remain constant with respect to strain over a specified range of strain (generally 3×10^{-3}), whilst an accuracy to at least $\pm 0.5\%$ is desirable. A method is described which allows the gauge factor to be read direct from the dial of the balancing device. In a bridge network, no direct measurement of strain being made. The method is best suited to production testing of gauges.

2. Analysis of the network

The basic circuit is shown in Fig. 1. P , Q are 'standard' strain gauges, having a known and constant gauge factor g ,

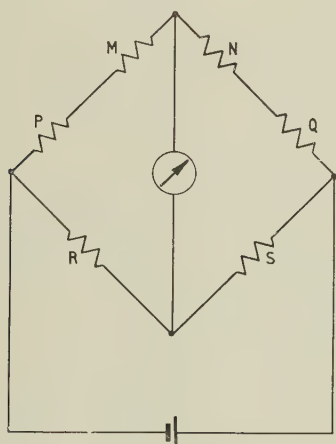


Fig. 1. Basic bridge circuit.

and are attached to opposite surfaces of the beam of the calibrator. R is the 'test' gauge, attached to the same surface of the beam as P , and having a gauge factor f , whilst S is a balancing resistance. M and N are ganged resistances, having initial values M_0 , N_0 .

The bridge is balanced initially when $M_0 = N_0$, $P = Q$ and $R = S$ and

$$(M_0 + P)S = (N_0 + Q)R. \quad (1)$$

If the beam is now bent P and R undergo strain ϵ (say)

whilst Q undergoes strain $-\epsilon$. If the bridge is rebalanced keeping $M = N$ then

$$\{M + P(1 + \epsilon g)\}S = \{N + Q(1 - \epsilon g)\}R(1 + \epsilon f). \quad (2)$$

Dividing (2) by (1), putting $M = N$, etc., and solving for f one finds

$$f = \frac{2Qg}{N + Q(1 - \epsilon g)}. \quad (3)$$

Now under any conditions ϵg is small with respect to unity and hence to a good approximation

$$f = \frac{2Qg}{N + Q} \left(1 + \frac{\epsilon g Q}{N + Q} \right). \quad (4)$$

Furthermore $\epsilon g Q/(N + Q)$ is generally very small with respect to unity and f may be written as

$$f = \frac{2Qg}{N + Q} \quad (5)$$

an expression that is independent of ϵ , and in fact is a function of N alone, Q and g being constant for a particular arrangement. To justify this last approximation, (4) is rewritten as

$$f = \frac{2Qg}{N + Q} \left(1 + \frac{\epsilon}{2} \frac{2Qg}{N + Q} \right) \quad (6)$$

and by replacing $2Qg/(N + Q)$ in the error term by f (from (5)) Eqn (6) becomes

$$f = \frac{2Qg}{N + Q} + \frac{\epsilon f^2}{2}. \quad (7)$$

Hence in using (5) the error made is $\epsilon f^2/2$, and for a practical case $f = 2.5$, $\epsilon = 0.003$ the error is about 0.009. This is within the acceptable error of 0.010.

In practice largely because of the difficulty in providing suitable resistances for M and N the circuit is modified as shown in Fig. 2, when U and V are fixed equal resistances and W is a variable resistance. A transformation of this part of the net can be effected resulting in

$$M = \frac{UW}{U + V + W} \quad N = \frac{VW}{U + V + W} \quad (8)$$

where M and N have the same meaning as in Fig. 1. In addition a resistance $UV/(U + V + W)$ is placed in series with the bridge balance indicator. Eqns (1) to (7) are therefore still applicable but (5) may be rewritten as

$$f = \frac{2Qg(2V + W)}{2QV + W(V + Q)} \quad (9)$$

where U has been put equal to V .

Typical approximate values associated with f in the range $2.5 > f > 1.67$ are $Q = 120$, $g = 2.5$, $V = 240$ and $480 < W < \infty$.

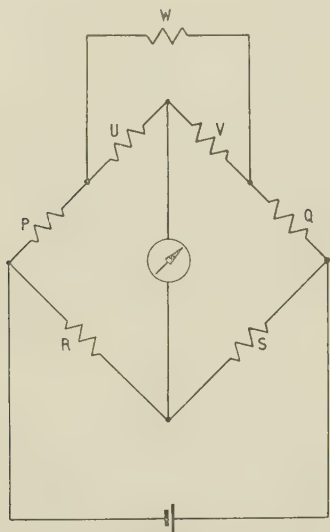


Fig. 2. Modified bridge circuit.

3. A consideration of errors

In practice the requirements that $P = Q$, $U = V$, $R = S$, etc., cannot be met exactly. Also, although all gauges can be made to undergo the same magnitude of strain, the 'standard' gauges may not have equal gauge factors. Hence the resulting errors must be considered.

Let the gauge factors of P and Q be g_1 and g_2 respectively, and let R and S be shunted by X and Y (large) respectively to obtain balance initially.

Then with $\epsilon = 0$ we have

$$\left(P + \frac{UW_0}{U + V + W_0}\right) \frac{SY}{S + Y} = \left(Q + \frac{VW_0}{U + V + W_0}\right) \frac{RX}{R + X} \quad (10)$$

After straining the gauges and rebalancing the bridge with W we have

$$\begin{aligned} &\left(P(1 + g_1\epsilon) + \frac{UW}{U + V + W}\right) \frac{SY}{S + Y} \\ &= \left(Q(1 - g_2\epsilon) + \frac{VW}{U + V + W}\right) \frac{R(1 + f\epsilon)X}{R(1 + f\epsilon) + X} \quad (11) \end{aligned}$$

Hence to a very good approximation (since $X \gg Rf\epsilon$)

$$\begin{aligned} f = &\left\{ \frac{P(1 + g_1\epsilon) + UW/(U + V + W)}{P + UW_0/(U + V + W_0)} \right. \\ &\left. - \frac{Q(1 - g_2\epsilon) + VW/(U + V + W)}{Q + VW_0/(U + V + W_0)} \right\} \\ &\times \epsilon^{-1} \left\{ \frac{Q(1 - g_2\epsilon) + VW/(U + V + W)}{Q + VW_0/(U + V + W_0)} \right\}^{-1} \quad (12) \end{aligned}$$

Now put $P = (1 + \phi)Q$, $U = (1 + \theta)V$, $U + V + W = \Sigma$, $U + V + W_0 = \Sigma_0$ and by ignoring second order terms, etc., (12) can be simplified to give

$$\begin{aligned} f = &\frac{Q}{(Q + VW_0/\Sigma_0)(Q + VW/\Sigma)} \\ &\times \left\{ (g_1 + g_2) \left(Q + \frac{VW_0}{\Sigma_0} \right) + \frac{V}{\epsilon} (\theta - \phi) \left(\frac{W}{\Sigma} - \frac{W_0}{\Sigma_0} \right) \right\} \end{aligned}$$

If now $g_1 + g_2$ is replaced with $2g$ the first term of (9) becomes very similar to (9), whilst if $W_0 = \infty$ (an easily realizable value in practice) the error term becomes

$$\frac{QV(\theta - \phi)(W/\Sigma - 1)}{(Q + V)(Q + VW/\Sigma)} \frac{1}{\epsilon}$$

and in the worst condition $-\phi = \theta$ and the error is

$$\frac{2\theta QV(W/\Sigma - 1)}{(Q + V)(Q + VW/\Sigma)} \frac{1}{\epsilon}$$

Now it can easily be arranged that for $f = 1.67$ $W = \infty$ and hence the error is zero except for $\epsilon = 0$. For $f = 2$, $W = 480$, $\theta = 10^{-5}$ and with the previously given values Q and V , W/Σ is 0.5 and $VW/\Sigma = 120$. Hence the error term becomes $3.33 \times 10^{-6}/\epsilon$. Clearly for the error term to contribute less than 0.01 to the value of f , ϵ must be greater than 0.333×10^{-3} . In practice the lowest value for ϵ is 1×10^{-3} , whilst the value assigned to θ is readily realizable.

4. Procedure for setting up network

Two pairs of Bakelite-based gauges (nominal resistance 120 ohms) were carefully matched for equality of resistance and attached using a phenolic resin adhesive to the upper and lower surfaces of the beam of the calibrator. After curing of the adhesive, a pair of gauges (P and Q) was selected whose resistances differed by no more than 0.01 ohm. A number of gauges was also attached to a brass specimen, selected gauges being used for the fixed resistances U and V .

The steel calibrating beam is supported at the quarter points and can be loaded at the extremities so that pure bending (with attendant constant surface strain) results over the portion of the bar between supports. The validity of this assumption was checked using an optical extensometer. In practice, strain in the beam is related to the radius of curvature of the beam, which is more easily measured.

The gauge factors for the standard gauges were determined by observing the fractional change in resistance of the gauges when subjected to known strains. Even if the strains in the standard and test gauges are not quite equal in magnitude, operation of the method is not seriously affected provided that the ratio of all the strains remains constant (see Eqns (12) and (13)). Clearly the accuracy of the method is limited by the accuracy with which these gauge factors can be determined.

By using a set of ratio arms with an accurate 1 : 1 ratio to replace R and S , and with $W = 0$, balance of the standard gauges is obtained if necessary with high resistance shunts. If the effect of these shunts is to reduce the gauge factor by a measurable amount, closer matching of the gauge resistances is indicated. With W disconnected, P and Q are similarly balanced. The bridge should now remain in balance for all W .

As V , Q and g are constant for a particular arrangement a table of values connecting W and f can be prepared. Hence resistance W can be either a decade resistance box or a set of switched resistances. In the latter case the switch positions can be marked in terms of gauge factor. The

balance network must not shunt the test gauge sufficiently to cause a measurable alteration in gauge factor suitable correction must be applied.

5. Concluding remarks

A new method for the rapid determination of gauge factor suitable particularly for production testing of gauges, has been described. In comparison with traditional methods of calibration it is faster (being essentially direct reading and requiring calculations for each test) and there is less possibility of error as only one reading is taken instead of two (although the strain will no doubt be roughly noted). The constancy of gauge factor is readily detected. This will appear as a bridge unbalance as the strain is changed with respect to the expected value. The results of tests conducted on a group of six gauges are shown in the Table. The maximum strain was about 1.5×10^{-3} , the gauges comprising a batch attached to determine the efficacy of a new method. Good agreement between the two methods is seen.

Acknowledgment

The author is indebted to the Chief Scientist, Australian Defence Scientific Service, Department of Supply, Melbourne, Australia, for permission to publish this paper.

Comparison of gauge factors obtained using two methods of calibration

Gauge No.	Gauge factor			
	Tension		Compression	
	A	B	A	B
1	1.99	2.00	2.00	2.00
2	1.99	2.00	2.00	2.01
3	1.85	1.83	1.87	1.87
4	2.02	2.03	2.03	2.03
5	1.99	1.99	1.99	2.00
6	1.99	2.00	2.00	1.99

- NOTE: 1. A refers to conventional method, B to proposed method.
 2. All results are the mean of two tests.
 3. Gauge No. 3 was found to possess a gauge factor variable with time and hence agreement is not as good as for the other gauges.

Measurement of friction between rubber-like polymers and steel

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Abstract

A machine for measuring the coefficient of friction between a flat sheet of polymeric material and a ground steel plate is described in detail. An inverted lathe cross slide forms the basis of the drive mechanism. Frictional force is balanced against the tension developed in a spring (proof ring), the extension of which, measured with a commercial displacement pick-up, gives a direct reading of coefficient of friction. A few results are given for a PVC sample plasticized with 40% di-octyl phthalate. A circuit for automatic operation and recording is also described.

KNOWLEDGE of the coefficient of friction of natural rubber has grown empirically over many years and compounds suitable for many different applications are available. The newer synthetic elastomers do not have this long history behind them and methods of measuring coefficient of friction are becoming increasingly important.

In most practical applications involving the friction of rubber-like polymers contact is made over an extended area. Numerous examples spring to mind; tyres, belting, footwear and flooring account for a vast amount of natural rubber and other elastomers. It seemed desirable therefore to design an apparatus which utilized an extended area of contact between the rubber and the other friction member.

An apparatus which utilizes a constant force to move the sample, such as that described by Schallamach (1952a) relies on the coefficient of friction of the system rising with increasing velocity. If this condition is not fulfilled the system is unstable and a servo mechanism has to be used to hold the velocity between two set limits. In this case the simplicity of the original system is lost and it is neither a constant force machine, nor a constant velocity machine. It was thought better to induce a constant velocity by other means.

It is acknowledged that the best way of maintaining a smooth motion at a steady velocity is by means of a hydraulic mechanism, and a machine for measuring the friction of metals, using this principle, has been described by Bristow (1947). A screw thread, although less accurate, is rather more convenient and therefore a lathe cross slide was made the basis of the RAPRA friction machine to be described here.

If the frictional force between the surfaces involved is balanced against the force developed in an extended spring then a measure of the spring displacement gives a reading proportional to frictional force. Under some conditions such a system is unstable and 'stick-slip' oscillations may develop. These have been extensively studied since the publication of Bowden and Leben's (1939) paper but an exact analysis depends on an accurate knowledge of the friction-velocity characteristics of the materials involved.

The phenomenon is much more marked at very velocities and Heymann, Rabinowicz and Rightmire (1958) described an apparatus for measuring friction at extremely low velocities where stick-slip motion was damped completely by means of a paddle immersed in a bath of oil. In a later article Rabinowicz (1958) showed that at a particular velocity stick-slip could be eliminated by increasing the spring force to a sufficiently large value. In any case a large spring force considerably reduces the amplitude of any vibrations present, even if it does not eliminate them completely and the spring dynamometer described by Pappas (1956) seemed very suitable for this application. The spring displacement is measured by means of a transducer and a commercial bridge unit. This is a very versatile system capable of handling a wide range of forces, and it has the advantage that the actual spring displacement is very small. The amplitude of any stick-slip vibrations is thus kept to a minimum.

Figure 1 shows an exploded view of the RAPRA machine and, as stated earlier, an inverted lathe cross slide L forms the basis of the drive. A $\frac{1}{4}$ h.p. induction motor coupled to a 4-speed gear-box gives final speeds of traverse of 1.36×10^{-3} cm/s in decades to 1.36 cm/s. The lathe cross slide is mounted on a rigid angle iron framework designed to fit inside a humidity controlled oven. The motor and gear-box are mounted externally, the coupling to the cross slide being made by a rod, fitted with two universal joints, passing through a rubber diaphragm at the side of the oven. The lathe cross slide carries a flat, ground steel plate G down the centre of which has been milled a shallow groove. Ten such plates were made and these, together with a flat, ground steel plate from another machine, are ground against each other in rotation.

The polymer being examined is moulded in a flat sheet about 1 mm thick from which are cut two samples measuring $7.5 \text{ cm} \times 2.5 \text{ cm}$. These samples are then stuck to a flat steel plate P, spaced apart so that they rest each side of the groove in the ground plate G. Plate P is dove-tailed so that it slides smoothly into the carrier C, being locked in position by the locking screw N. The sample plate can be removed and relocated accurately and this facilitates examination of the samples during the course of a series of experiments.

Ideally the link from the force measuring system should lie in the plane of friction, and the groove in the ground steel plate G and the divided PVC sample enable an approximation to this condition to be made. The rod R which is attached to the dynamometer is coupled to plate C by the pin joint. The position of the pin, which passes through the axis of the rod, is adjusted so that it lies in the plane of sliding. The condition which is maintained only if all samples used are of the same thickness. Plate C is connected by a similar

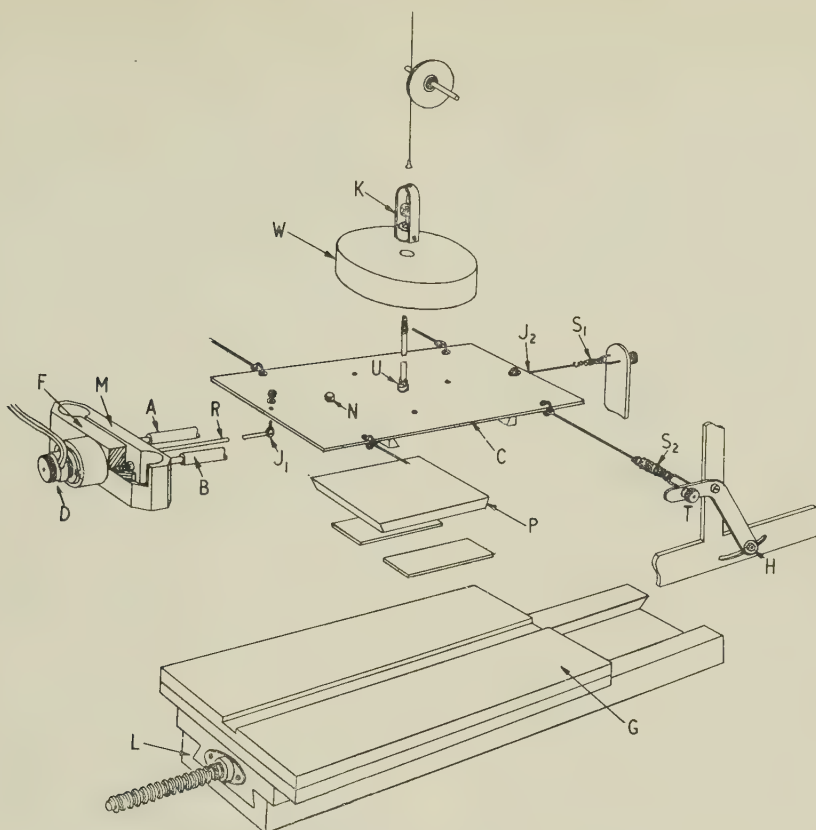


Fig. 1. Exploded view of RAPRA friction machine.

joint J_2 to a light spring S_1 , which is attached to the frame of the apparatus by an adjustable link. Sufficient tension is put on this spring to take up the back-lash in the joints, but the effect of this on the stiffness of the measuring system is negligible. The selection of spring tension corresponding to no frictional force is arbitrary and the measuring instrument has its own zero setting. It is worth describing the dynamometer in greater detail. The dynamometer spring (proof ring) consists of a block of mild steel, bored, slotted and shaped into a form which has greater flexibility in one direction than any other. Two rods A and B secured at one end to the framework pass through one side M of the spring and screw into the opposite side F. The cut-away portion of the diagram shows this more clearly. It is the moving side M of the spring that is attached to the rod R and the displacement of the moving side of the spring relative to the fixed side F gives a measure of the force developed. The commercial displacement pick-up D fitted to this particular apparatus is a differential transformer type with a moving ferrite core to which is attached a probe which touches face M and moves with it. Another, similar, tribometer has been fitted with a differential inductance type transducer and both have proved to be equally satisfactory. In either case the necessary oscillator, amplifier and balancing circuit are contained in a commercial unit loosely referred to as a 'bridge'. The instrument actually reads the displacement of face M relative to its rest position, but it is a simple matter to calibrate it in terms of force. To do this, rods A, B and R are disconnected from the apparatus and the dynamometer is mounted with rod R hanging vertically downwards. Weights can then be attached to R enabling a dead load calibration to be made. The sensitivity of this device can

be altered by machining the six flat faces at either end or by boring out the two holes. Once it has been brought to the right order, the sensitivity can be changed by an attenuator on the measuring bridge, which has six ranges from 3μ to 1 mm full-scale deflection. (Experience has shown that the sensitivity of a mild steel spring of this type may change slowly with time. This can be overcome by loading the spring slowly until the stress-strain curve is no longer linear and then removing the load. This work hardens the metal and stabilizes its characteristics considerably, although such a spring would be better made of a high tensile steel.) It should be mentioned here that while it would appear theoretically attractive to use a stiff spring and limit the deflection to 3μ , there are many practical difficulties involved. The whole system is very temperature sensitive under these conditions and although a shield against radiation and draughts helps somewhat, the slow rise in temperature of the bridge causes a steady zero drift and constant correction is needed. In practice it is better to use one of the higher ranges of the bridge; the improved stability thus obtained more than compensates for the increase in movement of the sample.

In order to zero the electronic bridge the sample plate must be suspended so that no frictional force acts on the sample. Near the centre of gravity of the plate C is a universal joint U with a short screwed rod attached to it. An adjustable connecting stirrup joins this to a length of steel cable, which after passing once around a pulley is taken out to a lifting mechanism. The knurled nut K is adjusted so that when the lifting mechanism is in its topmost position the sample is just clear of plate G. When the sample is lowered the cable is slack. If the two polymer samples are mounted

asymmetrically then the plate C will not balance. Also, any difference in the surfaces of the two samples may give rise to differing frictional forces, thus applying an unwanted couple. Both of these difficulties have been overcome by fitting four stabilizing springs to plate C. They are fastened at the other end by adjustable links to L-shaped levers mounted on the frame of the apparatus. One of the springs S_2 is shown in the diagram. The tension in this spring can be adjusted by means of the nut T and its height by means of the lever, which may then be clamped with nut H. The tensions in the four springs should be very low in the rest position, but any tendency for plate C to turn under the action of asymmetrical frictional forces is immediately countered by a powerful opposing couple. As the actual displacement of plate C is very small the lines of action of the four stabilizing springs are always normal to the direction of motion, and their effect on the friction measuring system is negligible. Any slight lack of balance of plate C in its free position may be corrected by altering the heights of the springs. To do this, the lifting cable is disconnected and a fine thread fastened to the stirrup in its place. This thread is then passed over the pulley and a counterweight attached which has a weight equal to plates C and P, including the samples, and an allowance for that part of the weight of springs S_1 , S_2 , etc., and rod R supported by the plate. By tapping plate C in each of the four corners in turn it is easily ascertained whether or not the corners of the samples are in contact with plate G. The four L-shaped levers are then adjusted until the samples are uniformly clear of the ground steel. With care it is possible to make this adjustment so that a 5 g weight placed on any corner will bring it into contact with G. When this has been done the levers are locked in position and no further adjustment is necessary.

The normal load applied to the sample is a cylinder of steel W, drilled so that the rod attached to the cable can pass through it, and fitted with three pegs which form an equilateral triangle, each peg being equidistant from the centre of gravity. These pegs fit into dimples on plate C, the whole being carefully adjusted for balance before assembly.

After plate C has been levelled, the position of the pulley is adjusted so that the cable is exactly vertical. To do this the counter-balance weight is first removed, the load W applied, and the steel cable attached to the stirrup after passing once around the pulley. With the plate C being automatically raised and lowered, the position of the pulley is adjusted until the electronic bridge reading does not alter appreciably in the high and low positions. If the initial balancing of C is even slightly in error then one corner of the sample may touch the ground steel plate too soon and the resulting frictional force gives misleading readings. This may be avoided by inserting two polished steel rods between C and G so that the polymer samples never quite touch the steel plate. It is an easy matter to make this adjustment so that the force reading does not alter from zero by more than 20 g.

Preparation of samples and ground steel plate

It is self-evident that the friction between two substances will vary with the surface condition of the samples, and it is essential, therefore, that all surfaces are brought to some standard condition before measurements are made. After being machined, three steel plates (two ground flat stock and one mild steel) were scraped and checked against a grade B surface plate until they were as flat as this method of testing would indicate. They were then ground one against another by hand using a dispersion of grade IF

carborundum in Teepol* until all scraping marks had disappeared. After being rinsed in running water two of the plates were ground together again with a rotary motion (circles of about 2 in. diameter), using fresh carborundum and Teepol, giving fifty rubs and then turning one plate through 90°, fifty more rubs and a further rotation and on until a count of 200 was reached. One plate was then immediately rinsed in hot running water and while still hot flooded with acetone so that drying was accomplished within five seconds. This was found to be essential as a steel surface was very active after grinding and rusting occurred within one minute if the steel was left wet in water. All steel plates were retreated in this way before a new sample was tested.

A moulded polymer surface, even if nominally flat, liable to be contaminated with mould release agent or other impurities. To overcome this trouble all samples after mounting on the sample plate P have been ground on number 0 glass paper backed by a surface plate. When the surface appeared uniform to the eye, the glass paper was changed and a further fifty rubs given with a rotary motion on this fresh surface. Loose dust was then brushed from the polymer surface with a clean toothbrush. After this stage samples have been given different treatments. Some were tested directly after brushing, others were first scrubbed in running water and then allowed to dry before testing. Others again were rinsed in acetone and then allowed to stand overnight before testing. None of these treatments was found to have any appreciable effect on the coefficient of friction provided that the samples were given time to reach equilibrium. Treatment with acetone considerably increases the coefficient of friction of plasticized PVC on steel, for example, but as the acetone evaporates and the swollen PVC recovers the coefficient of friction steadily falls until after about three hours it is back to its former value.

It has been found that running the machine first in one direction and then in the other and measuring the coefficient of friction on each occasion gives erratic results. More consistent and reliable results are obtained by making measurements in one direction only, when the dynamometer system is under tension, the ground steel plate being returned with the polymer sample in the raised position. All measurements have therefore been done in this way and each forward journey is referred to as a run.

Very frequently the first few measurements of coefficient of friction using freshly ground samples and a freshly ground steel plate do not agree with each other. Usually the coefficient of friction falls. If measurement is continued the difference between successive readings becomes less until eventually a constant value is reached. All samples have been subjected to this running-in process before further measurements have been taken. This is not entirely satisfactory as will be explained later, but the only alternative is regrinding before individual measurement, a time consuming process, and one which bears no relation at all to service conditions.

It is inevitable that a certain amount of wear takes place between rubbing surfaces and this leads to various forms of debris collecting. This can alter the coefficient of friction considerably and may in part account for the change in friction which occurs when newly ground surfaces are rubbed together. The formation of an abrasion pattern on a polymer surface is common and the method of running in one direction only which has been described enhances and

* Shell Chemicals Ltd.

tern which may be formed. Schallamach (1952b) has pointed out that the rate of wear is very much greater when a pattern is present, and this must also influence the coefficient of friction. Often associated with an abrasion pattern are small rolls lying at right angles to the direction of motion and these have been described previously by James (1959). When rolls are present the rate of wear can be very high and consequently the coefficient of friction changes. If the deformation of the rolls and of the polymer surface is small, then they act as a lubricant and the coefficient of friction is considerably reduced. If, however, the rolls or the polymer surface are noticeably deformed then the hysteresis loss in moving forward appears as frictional work done and the coefficient of friction is consequently higher than it would be if rolls were absent. Friction measurements are always confused by wear to some extent, but in the case of polymers this can be a major source of error. It can be overcome to some extent by brushing loose debris from both the samples and the ground steel plate but some debris cannot be removed by brushing or even by scrubbing under running water. It is possible to remove it in one of two ways, either by regrinding the sample or by rubbing it with a fluffless cloth wetted with acetone. If this latter method is used then the sample must be left for several hours before further testing.

Test conditions

In order that measurements might be made over a wide range of conditions the whole apparatus, apart from the dynamometer, was mounted in a humidity-controlled oven. The large mass of metals involved took rather a long time to reach an equilibrium temperature and therefore three thermometers were used to check that temperature gradients were absent. A small Rotatherm thermometer was mounted on the cross slide itself and two mercury in glass thermometers were situated at opposite ends of the oven. One of these measured the air temperature and the other was mounted in a large block of brass screwed to the frame of the apparatus. Measurements were not carried out until all three thermometers agreed to within 1°C . The weight had a very large thermal capacity and subsidiary experiments showed that it took a longer time to reach equilibrium than the rest of the apparatus. Fortunately the three catering pegs gave very little thermal contact with the plate which remained unaffected by the temperature changes of 1°W .

Trays containing saturated solutions of various salts were used for humidity control and the published figures were checked from time to time with a dew-point hygrometer. In spite of careful sealing of all outlets the actual relative humidity obtained was often up to 5% lower than the published figures.

Stick-slip vibrations

It has not proved practical to damp out all stick-slip vibrations and this troublesome phenomenon has interfered with measurement from time to time. An exact analysis of stick-slip trace is not easy and few workers have attempted it. Sampson *et al.* (1943) performed such an analysis and showed that friction may not be uniquely dependent on velocity. Dudley and Swift (1949) have shown that the appropriate differential equations may be solved by graphical means provided that the friction-velocity curve is already known. In most published analyses friction is assumed to be a function of velocity only. This leads to a solution which gives vibrations of an amplitude which is independent

of velocity, but experience shows that this is incorrect. In general the amplitude of stick-slip vibrations increases as the velocity is decreased. Ishlinskii and Kragelskii (1944) explained this phenomenon by assuming that static friction was time dependent. In addition, Rabinowicz (1958), in his survey of factors affecting the stick-slip process, suggests that there is a critical displacement necessary before vibrations will occur. It seems likely that friction is a function not only of velocity, but of acceleration also, but the exact nature of this dependence is not known. Our recording system was not sufficiently fast to enable accurate force-displacement curves to be obtained and therefore no exact analysis has been tried. It is easily shown that the coefficient of friction corresponding to the mean relative velocity lies between the limits shown on a stick-slip trace and the simplest solution gives it as the mean. In all plots where stick-slip has occurred it is the mean value of coefficient of friction that has been taken, although it is realized that this is probably in error. When one of the components in a sliding system is a polymer, it can, in fact, act as its own spring as was demonstrated by Papenhuzen (1938). Energy is stored in the sheared polymer which further complicates the stick-slip analysis. Any theoretical treatment of stick-slip vibrations must be to some extent divorced from reality as assumptions must be made which render the differential equations soluble. It is therefore unwise to interpret according to a particular theory results obtained in practice unless the dependence of friction on both velocity and acceleration is known.

Automatic operation

In order that a large number of measurements might be recorded with a minimum of attention the apparatus has been designed to run automatically. Provision has been made for the automatic cycle to be interrupted so that unusual experiments might be carried out, but it is not proposed to describe the circuit in great detail and a simplified version is shown in Fig. 2.

The main drive motor is shown as two separate coils, the smaller one being for starting. A centrifugal switch disengages this coil when the motor reaches its running speed. The chart motor of the recorder is coupled to the main motor in such a way that it operates only when the main motor runs in reverse. The motor which lifts and lowers the samples has a cam on its shaft which operates two micro switches Ms_1 and Ms_2 .

The cross slide and plate G travel between the limit switches Ls_1 and Ls_2 . Consider the condition where the cross slide is moving in the direction marked forward, with the sample lifted clear of the ground plate G (referred to as the weight up position). In this condition relay H is off and the chart motor is stationary; no friction measurement is being made. When the cross slide reaches the limit switch Ls_1 the main driving motor is switched off and relay H is energized, changing contacts HABC and D to position R. There is then a current path to the weight motor which lowers the samples and continues to rotate until the cam-operated switch Ms_2 changes to position D. Almost simultaneously cam-operated switch Ms_1 changes to position D and the main drive motor is again energized. Contacts HA and HB have already reversed the starter coil connections of the drive motor so that the cross slide now travels towards Ls_2 . The sample has been lowered and the friction between the polymer and the ground steel plate is measured by the dynamometer. The chart motor is now receiving current and a permanent record of the variation of kinetic friction

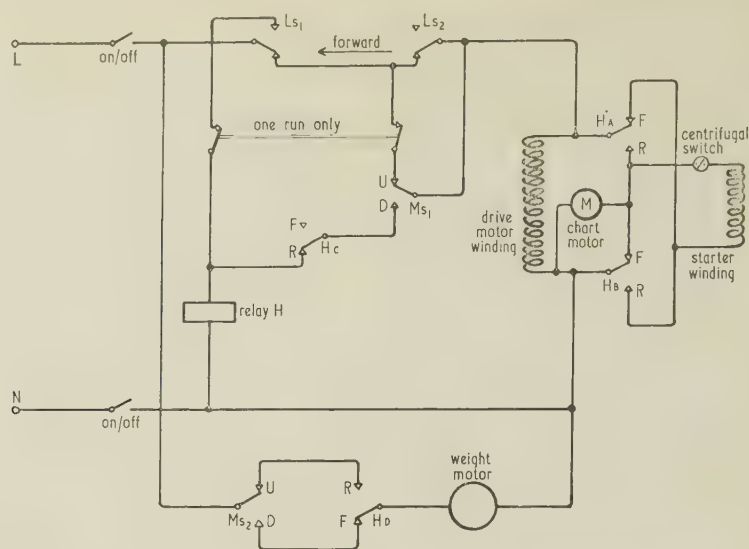
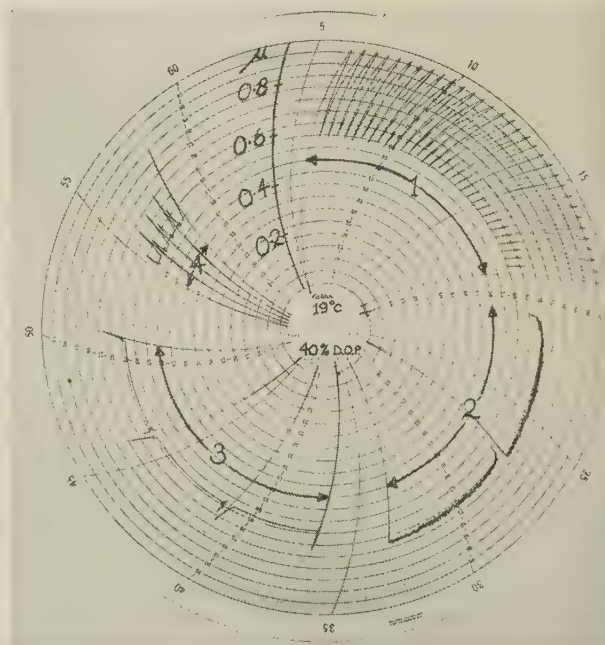


Fig. 2. Circuit of automatic control unit.

with time may be taken. The time constants of the circuit are so arranged that when the slide leaves switch Ls_1 the relay H does not drop out. The inertia of the main motor is sufficient for the change over of the current supply path to pass unnoticed. When the slide operates switch Ls_2 the current to the main motor is interrupted once more and relay H is released, contacts HABC and D changing to F again. The weight motor now lifts the sample and rotates until cam-operated switch Ms_2 changes to position U. Almost simultaneously switch Ms_1 changes to position U and the main motor operates again, this time with contacts HA and HB in position F. The slide now moves in the forward direction and the cycle is complete. The carriage can be stopped at either end by operating the switch marked 'one run only'. The other manual switches have been left out for the sake of simplicity.

Results obtained

The apparatus has been used mainly to study the friction of various PVC compounds in contact with steel. Some typical traces are shown in Fig. 3. In general the agreement between results obtained from a series of consecutive runs at the same velocity is remarkably good, the variation in coefficient of friction being not greater than ± 0.02 . If the gear ratio is changed while the apparatus is running then a change of coefficient of friction with velocity of $\pm 2\%$ can be recorded with ease. The agreement between nominally identical samples run under nominally identical conditions, or between the results obtained from the same sample at widely separated times is not so good. Differences of 20% are common and even larger variations occur at temperatures in excess of 50°C . This is probably due to uncontrollable variations in the surface condition of the samples, e.g. the amount of plasticizer present on the surface. It has already been pointed out that surface debris can greatly alter the coefficient of friction. Because of the uncertain nature of the PVC surface it is not possible to make a single measurement of coefficient of friction and state the result with any degree of certainty. A large number of measurements must be made and all possible variations in surface condition carefully checked. Some previous results were discussed in

Fig. 3. Coefficient of friction-time chart, at 19°C for PVC with 40% di-octyl phthalate.

1. Stick-slip trace at a velocity of 0.00136 cm/s . Chart speed 6 rev/h.
2. Two consecutive runs at a velocity of 0.0136 cm/s . Chart speed 1 rev/h. Note the greatly reduced amplitude of the stick-slip vibrations.
3. Three consecutive runs at a velocity of 0.136 cm/s . Chart speed 6 rev/h.
4. Four consecutive runs at a velocity of 1.36 cm/s . Chart speed 6 rev/h.

a paper by James *et al.* (1959) and further work will be presented in later papers.

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New instruments, materials and tools*

Transistorized 30 A power supply. Invar Electronics Corp., 323 W. Washington Blvd., Pasadena, California.

This is a completely transistorized stabilized power supply giving 0–36 v at 30 A max current. The unit has complete electronic short circuit protection, a variable maximum current adjustment and remote sensing terminals. Optionally available are over-voltage protection and provision for remote programming.

Regulation against mains variation is 10 mv max; load regulation 5 mv max; and ripple to 1 mv max. The unit is 11 in. high, 19 in. wide and 20 in. deep. Model number TP-30.

Autoclave filter. E. N. Mackley & Co., Hawks Road, Gateshead, Co. Durham.

It has been established that cotton wool is an unsatisfactory medium for filtering the air which is drawn into a sterilizer autoclave on breaking the vacuum at the end of the sterilizing cycle, since it allows the passage of bacterial and virus contamination. The filtration medium of the Mackley autoclave filter is a rot and insect proof 'paper' made entirely from glass fibres of approximately 1 micron diameter. It is claimed that these filters are for all practical purposes 100% efficient. Each is tested in accordance with B.S. 2831 : 1957 and any having a penetration of methylene blue higher than 0.001% are rejected. Biological tests show that air filters

with a methylene blue penetration of less than 0.003% are 'absolute filters' in respect of bacteria and virus.

The filters will fit all makes of steam sterilizers and autoclaves. A critical orifice in the support tube ensures uniform air flow and prevents excessive strain on the filter. A fine mesh dust cover, detachable for cleaning, protects the filter from clogging by atmospheric dust.

Fast tungstate screens. Ilford Ltd., Ilford, Essex.

A new salt intensifying screen, the Ilford Fast Tungstate Screen has just been produced which is of particular significance in the light of the recommendations given in the recently published report of the Adrian Committee* that the fastest materials consistent with satisfactory diagnostic value should be used.

These screens are twice the speed of the Ilford standard screens at all voltages and with negligible loss in definition. In fact due to the possibility of minimizing the effect of subject movement by the use of shorter exposure times, definition may be better than with the standard screens.

The screens also effect an improvement in definition by allowing the more widespread use of fine-focus x-ray tubes. They are also of particular value in mobile equipment where equipment of limited output is used.

* 'Radiological Hazards to Patients.' Ministry of Health and Department of Health for Scotland. Second Report of the Committee, H.M.S.O., 1960.

See p. 309

Electrical micromanometer

by H. R. HART, Dominion Physical Laboratory, Department of Scientific and Industrial Research,
Lower Hutt, New Zealand

MS. received 21st June 1960, in revised form 20th February 1961

Abstract

An instrument is described for measuring differential pressures in the range 10^{-4} to 1.0 in. water with high accuracy. Minimum reliable indication of 10^{-6} in. water has been obtained in calibration. The instrument is null reading for extreme accuracy, but is also designed for direct recording and portability.

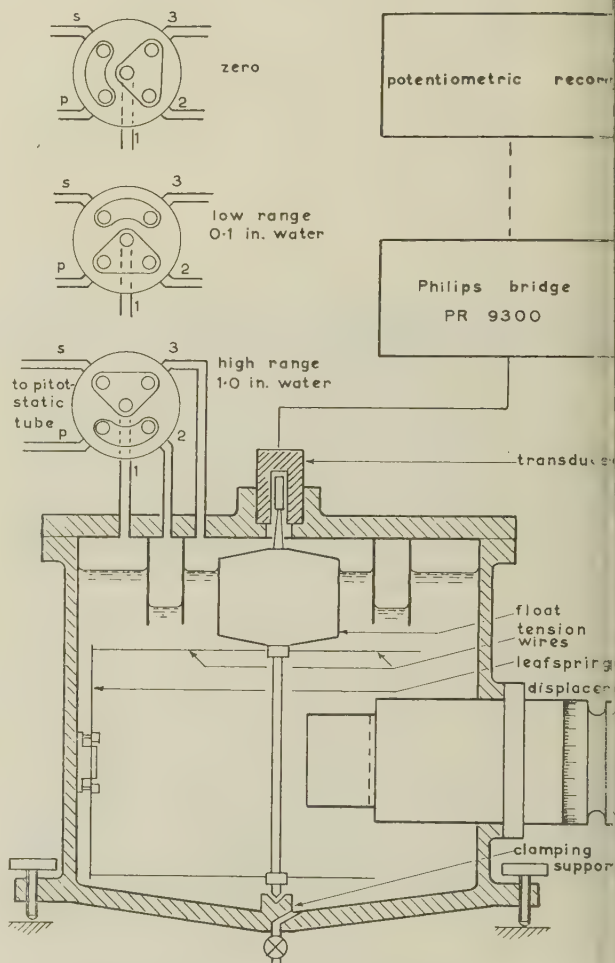
1. Introduction

A NEW type of manometer, which has several interesting features, has been developed for use with a Pitot static tube for measuring air speeds in a wind tunnel for anemometer calibrations. The manometer was developed because air speeds in the range 0.3 to 70 ft/s could not be measured with sufficient accuracy by available commercial instruments. The new instrument combines quick response with multiple range, high sensitivity and great accuracy, continuous recording and ease of operation, and has performed satisfactorily for more than a year.

2. General arrangement

The complete instrument, shown diagrammatically in the Figure, consists of a concentric manometer with a three-position valve, and an electrical bridge with an indicating meter or a continuous recorder. When a pressure difference is applied, the rise in level of the fluid (toluene) in one 'limb' of the manometer is detected by a float that displaces the core of a sensitive induction transducer connected to the bridge and indicator. The rise of the float is, of course, less than the actual pressure head by a factor depending on the relative areas of the two annular 'limbs' of the manometer. Float movement is limited to 2 mm because of the transducer. This movement can arise either from a pressure of 1.0 in. water or of 0.1 in. water, depending upon the setting of the valve that links three compartments in the manometer and controls the ratio of 'limb' areas. Larger pressures may be measured with a pressure divider (Cohen 1948).

For calibration purposes the rise corresponding to any given pressure can be imitated by making a suitable volume change with one or other of two displacer pistons. In the present instrument these are fully immersed in order to avoid meniscus errors, and their controlling micrometers are scaled to read pressure directly. The most important feature of the instrument is that for precise measurements the displacer pistons can be used to annul the change produced by an applied pressure, using the bridge indicator to show the null position. Thus the accuracy depends upon the dimensions of displacers and limb areas alone; the transducer and associated equipment merely being used to detect the null point.



Diagrammatic arrangement of electrical micromanometer.

Friction in the moving parts is avoided by using fine tensile wires to locate the float.

3. Constructional details

The manometer body is a 9½ in. diameter cast bronze cylinder internally machined, polished and acid etched. Leaks due to porosity in the base of the casting were successfully sealed with urea formaldehyde (Hudson 1948). Two concentric brass cylindrical walls, which were given the same surface treatment as the body, are screwed to the underside of the lid. A 2½ in. diameter cylindrical brass float is attached to a stem fitted at its upper end with a Ferroxcube core Philips displacement transducer (type 5537). Below the float

0.003 in. differential wires, fitted between the stem and three ii-spaced leaf springs attached to the inside of the manometer body, ensure that the float moves on the vertical axis y. Leaf-spring tension is initially adjusted so that the transducer core moves freely within the transducer. The float is clamped for safety in transit by spring fingers (not shown in the diagram), which bear on it. These clamping fingers are operated by a button fitted to a sealed push rod. When depressed, the lower end of the float stem engages a vertical clamping support. The instrument is quite portable when clamped and drained and is not easily damaged. Sealing screws are provided. Displacers consist of lapped steel pistons operated by micrometers. Pistons are spring-loaded to obviate backlash, and pass through polytetrafluoroethylene glands. Each micrometer division of the small displacer corresponds to a pressure difference of 10^{-5} in. water, whilst the total displacement of the large displacer corresponds to a pressure of 1 in. water. To reduce the effects of vibration the micrometer rests on a thick steel plate on top of a stack of concrete slabs, each of which is separated from its neighbours by pieces of rubber. The bridge (Philips, type PR9300) has been modified by changing the mechanical and electrical balance points from centre zero to left-hand zero in order to attain maximum meter movement for a rise of pressure. Different sensitivities appropriate to the pressure difference or air speed to be measured are achieved by changing the bridge amplification with an attenuator, and by choosing the suitable setting of the three-position valve. The meter has four air-speed scales and one linearly divided scale for pressure measurement. Air-speed readings at any barometric pressure or temperature are reduced to standard readings (i.e. 30 in. Hg and 60° F) by adjustment of two variable rheostats in series with the meter. As an alternative to direct indication, a continuous pen record may be taken of the potential drop across a resistance replacing the indicator.

The three-position face valve (shown diagrammatically) is a rotatable nylon disk with a triangular and an arc-shaped port, and is spring-loaded on to a flat, lapped steel plate to which five connecting tubes are fitted. As well as the positions appropriate to maximum pressure differences of 1.0 in. and 0.1 in. water, there is one for establishing the zero by equalizing the pressures in all three limbs of the manometer.

4. Choice of fluid

Changes of meniscus shape of manometric fluids place a limit on reproducibility of float position. Tests were made, using a shadow projector, to find a suitable liquid, and the best surface condition for parts in contact with the liquid. Fluids tested included tap water, distilled water, kerosene and toluene. Wetting agents were added to the water. Best performance was obtained with toluene on surfaces which had been lightly etched. No changes in meniscus shape were observed when test rods were moved into or out of the liquid, regardless of the amount or rate of movement. Further, pure toluene is readily available, and its density is accurately known (0.8658 at 20° C) (*International Critical Tables* 1926). The vapour pressure at 20° C is only slightly higher than that of water, but its coefficient of expansion is six times as great, so that for good stability the temperature of the instrument should be kept constant to within, say, 1° C.

5. Performance

The response time of the manometer is mainly controlled by the restriction to airflow in the associated apparatus. For

instance, with an N.P.L. $\frac{5}{16}$ in. Pitot-static tube, at an air speed of 10 ft/s, the indicator develops nine-tenths of its final reading within 7 seconds. Because of its high sensitivity and relatively fast response, unsteady wind speeds or pressures can result in fluctuating readings. These can also arise if, because of the internal geometry of the associated apparatus, pressure waves in the two connecting tubes arrive out-of-phase at the manometer. Ower (1949) describes a remedy in which one tube is restricted by trial and error until the waves arrive simultaneously and compensate each other.

The moving system is remarkably stable, for, despite the small clearance between moving core and transducer body, it has not been necessary to make any leaf-spring adjustments since the manometer was originally assembled. Small tilts do not cause interference between moving parts. The spring rate of each float spring is about 3 g/cm, and after the support wires were tensioned the loss of float movement was found to be 2.5%. Maximum meter deflection is therefore 2.5% less than with a completely free float. Since the indicator is calibrated against the displacer, this constant loss of sensitivity is automatically allowed for. Pressure readings obtained by the 'null' method, i.e. by moving displacers and keeping indicator at one setting, obviate errors due to possible changes of sensitivity and also those due to quasi-hysteresis, non-linearity, etc., which are always liable to be present in a direct-reading system.

Movement of the large displacer was measured in an optical projector, and over the whole range of movement (1 in.) the error at any point, with increasing or decreasing readings, is less than 0.0002 in. Similar results were obtained with the small displacer. It is understood that the lens of an optical projector itself sets a limit of ± 0.0002 in., and that modern commercial micrometers are much better than this.

The bridge output on its most sensitive range is 180 mv for a differential pressure of 0.001 in. water, corresponding to full-scale deflection of the meter. The output at 10^{-6} in. water is thus 0.18 mv, which is easily measurable on a suitable potentiometer. Pressure differences of 10^{-5} in. water have been simulated by moving the small displacer by one division. Minimum reliable indication was found to be about 10^{-6} in. water when the instrument was kept at constant temperature. Variations of temperature cause readings to drift (due to expansion of toluene) so that where a continuous record of pressure is wanted constant temperature must be maintained, or else the valve must be turned to give zero readings at frequent intervals. Under ordinary laboratory conditions the large thermal capacity of the manometer makes its rate of drift small enough (0.001 in. water in 10 minutes, say) to be neglected when measuring air speeds for calibrating anemometers.

Accurate readings of low, but fluctuating, pressures have been attained by a combination of null and direct reading. Most of the pressure difference is annulled by the displacer(s), and the remaining fluctuating difference is recorded. This recorded portion of the pressure difference is usually small and high amplification can be used. The total pressure difference is thus the sum of the displacer reading and the recorder reading. (In general it is the average value of the recorder reading that is required.)

6. Conclusions

The basic accuracy of the instrument depends on the dimensions of various simple bodies which can be accurately measured by ordinary metrological techniques. Behaviour

of manometric fluids has been studied and toluene proved satisfactory. The manometer has been transported many times within the laboratory and has given satisfactory performance since manufacture over a year ago. Because of its accuracy, range and ability to record, this instrument is thought to be a significant advance in micromanometer design. The manometer could readily be made elsewhere, given good workshop facilities, and fuller details are available (Hart, 1960, Dominion Physical Laboratory Report No. 293).

Acknowledgments

The author is grateful to the staff of the Dominion Physical

Laboratory for help in the successful development of electrical micromanometer.

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New Instruments, materials and tools*

Operational amplifier type A2. Fenlow Electronics Ltd., Springfield Lane, Weybridge, Surrey.

The type A2 is a completely transistorized chopper-stabilized amplifier incorporating an auxiliary drift correction channel which makes use of a new chopper transistor. The chopper drive waveform is obtained from a multivibrator which is incorporated in the amplifier case. It gives a large output voltage swing and is particularly suitable for analogue computer applications for amplifying, sign reversal and integrating.

Typical drift 200 μV ; noise less than 100 μV ; bandwidth open loop 1 kc/s. Size $5\frac{3}{4}$ in. $\times$ $1\frac{1}{8}$ in. $\times$ $4\frac{1}{4}$ in.; heating negligible.

Mercury cleaner. Loughborough Glass Co. Ltd., Loughborough, Leicestershire.

Suspended impurities are removed from contaminated mercury by this apparatus which can handle up to 3 lb of mercury per minute.

The cleaner consists of a Perspex body and cup with a central well through which the mercury is decanted into a storage jar beneath. In the well is a gold seal which, when wet with mercury, forms a positive seal through which sus-

pended contaminants cannot pass. An acetate strip is placed in the well as a vortex breaker.

Before the contaminated mercury is poured into the cup a small amount of clean mercury is placed in the central well to prime the cleaner.

New nickel steel. The International Nickel Co. (Mond.) Ltd., Thames House, Millbank, London, S.W.1.

The new steel has a nominal composition of 18% nickel, 7% cobalt, 5% molybdenum and less than 0.5% titanium with a maximum of 0.05% carbon.

The material has the ability to achieve a yield strength of over 250 000 lb/in.² while maintaining a nil ductility transition temperature below -80°F . The notched tensile strength exceeds 400 000 lb/in.² measured with a notch radius of 0.0005 in. and the alloy has a high resistance to delayed cracking when stressed in a highly corrosive atmosphere.

The alloy develops its strength by means of a heat treatment which consists, with proper finishing temperatures off the mill followed by air cooling to room temperatures, of holding for about three hours at 900°F and air cooling. Solution annealing at 1500°F prior to this treatment is optional. Quenching is not required, and full properties can be developed in heavy sections with no distortion problems.

*See p. 309

Method of density determination on a micro-scale

J. M. JONES, M.Sc., Department of Geology, King's College, Newcastle upon Tyne

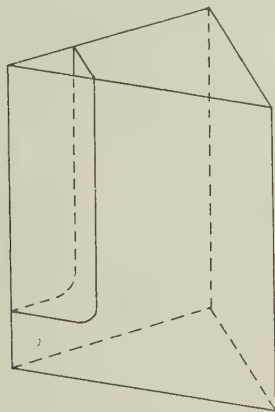
received 27th March 1961

Abstract

A sample is suspended in a liquid of graded density contained within a hollow prism. This permits the determination of the refractive index of the liquid at the level of the suspended sample, from which the density of the liquid, and therefore of the particles, may be obtained.

DURING recent investigations into the physical properties of the coal macerals, it has been necessary to determine the densities of samples having a mass less than 10 mg. The difficulties resulting from the small sample and the high porosity of the material have been overcome by the following procedure.

A hollow prism is constructed by grinding away a portion from the apex of a glass former and cementing a pair of clear glass slides to the faces (see the Figure); the angle of the



hollow prism in which the graded density column is established.

The angle of the prism is not critical. The cavity formed in the prism is initially filled with dilute Thoulet's solution (Thoulet 1879), an aqueous solution of potassium mercuric iodide, and after the addition of a further quantity of less concentrated solution, the two are carefully mixed so as to produce a column of graded density. Due to the narrow form of the prism, $1\frac{1}{2}$ in. $\times$ $\frac{1}{4}$ in., the gradation produced is very stable. After grinding to pass 72 mesh, the material under investigation is placed in the graded density column and allowed to settle into a band at its equivalent density level. Only a very small quantity of the sample need be used, sufficient to form a discernible band. This operation is carried out on the stage of an optical goniometer, which has been slightly modified by positioning an horizontal slit between the goniometer and the prism. This is in addition to the original vertical slit in front of the collimator, the image of

which is used in the measurement of the angle of the prism and the determination of the refractive index of the liquid in the prism by the minimum deviation method.

The horizontal slit is carefully aligned with the cross-wires of the goniometer eyepiece; its purpose is to restrict the light to a narrow horizontal beam, so as to restrict the determination of the refractive index of the liquid in the graded density column to the level of the suspended particles. The telescopic eyepiece of the goniometer permits an accurate alignment of the band of particles with the eyepiece cross-wires and therefore with the light beam from the collimating system.

The horizontal slit should be as narrow as possible, consistent with adequate signal strength; excessive width increases the portion of the column traversed by the light beam, with consequent blurring of the image due to the variation in the refractive index of different levels of the graded density column. Under correct working conditions the signal, which is the image of the vertical slit (since the horizontal slit is not in the focal plane of the eyepiece) should be tilted slightly because of the greater deviation of the lower portion of the light beam than the upper during its passage through the column; providing there is no blurring of the signal this will not affect the accuracy of the instrument. Irregular gradation of the column, resulting from inadequate mixing of the two solutions, will be indicated by a confusion of the signal. The measurements are carried out in sodium light.

Having obtained the refractive index of the solution at the level of the suspended band of particles, and the linear relationship between the density and the refractive index of the suspension solution having been determined, the density of the liquid and therefore of the particles may be obtained. Thoulet's solution, with a maximum density of 3.2 g/ml, has been used in the present experiments with the coal macerals and has been found satisfactory for a wide range of other materials.

Once the refractive index-density relationship of the solution has been established and the angle of the prism measured, only the angle of deviation need be obtained in order to calculate the density of the sample; this requires a single measurement on the goniometer.

If the sample under examination is porous it should, after crushing to pass 72 mesh, be divided into two portions, each of which is evacuated for an hour, one in water, the other in dilute Thoulet's solution. This procedure enables a correction to be made for the porosity of the sample, since after evacuation in water alone the pores of the material will be filled with water and a low density value obtained for the suspended particles; there is virtually no interchange between the liquid in the pores and that in the prism. From the results obtained after evacuation in two media, the density

of the material when evacuated in a solution of density equal to its own can be calculated.

$$\frac{d_s - d_{s,w}}{d_s - d_w} = \frac{d_{s,T} - d_{s,w}}{d_T - d_w}$$

where d_s = the true density of the sample
 $d_{s,w}$ = density of the sample after evacuation in water
 d_w = density of water
 $d_{s,T}$ = density of the sample after evacuation in Thoulet's solution
 d_T = density of Thoulet's solution.

The densities of the evacuating solutions are also determined in the prism after the evacuation of the sample.

An accuracy of measurement to $\pm 0.05\%$ is achieved with this method of density determination and satisfactory results

have been obtained for many minerals, such as the feldspars, in addition to the coal macerals; variation in temperature within the normal range, has no discernible effect upon accuracy. The method is rapid and has the advantage of excluding impurities and contaminated particles from the determination, often an important consideration in petrological work.

Acknowledgment

This work forms a part of the National Coal Board Extra Mural research programme, which is carried out by the Department of Geology, King's College, Newcastle upon Tyne.

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New Books

The electron microscope: the present state of the art. By M. E. HAINE with a chapter in collaboration with V. E. Cosslett. (London: Spon, 1961.) Pp. xvi + 282. Price 55s.

There are comparatively few books on the electron microscope and, although the fundamentals of electron optics are accessible enough to students and research workers, yet much information on design and manipulation is still only to be found in journals and in the published proceedings of the four international conferences on electron microscopy. Dr. Haine's book fills the role of providing the newcomer with some of this up-to-date information. It also supplies the workers in the field with useful data in a handy form.

Magnetic lenses and their defects are first discussed and then the book leads on to chapters on image contrast and practical limitations in performance. The treatment of contrast mainly follows the lines of a paper published by Dr. Haine in volume 57 of this Journal. For biological work, the attainment of good contrast in araldite-embedded specimens is probably more of a problem than high resolution and many biologists are now trying to enhance contrast by staining their sections with uranium or lead compounds. But a physical understanding of how electron micrograph

contrast depends on such factors as atomic number, beam voltage and objective aperture is a worth-while study for all microscope users. It may be noted that the book shows two misprints in the first column of Table 4.2, where '4' and '416' should be replaced by '4' and '16'. Later chapters go on to describe the design of an electron microscope, with the discussion mainly centred on the EM6 model of the Associated Electrical Industries. The final chapter, written in collaboration with Dr. V. E. Cosslett, describes specimen preparation. Replica techniques are dealt with at some length, biological applications are described, perhaps wisely, with detailed recipes of the fixing and embedding procedures; concluding paragraph describes the work of Menter and Pashley on the direct resolution of crystal lattice planes.

The value of this book to the non-specialist or beginner might be enhanced if a brief general outline of the essential features and optics of a simple electron microscope could be introduced at the very start, indicating the positioning of the three lenses, the two lens apertures, the specimen, the eyepiece and the screen. Nowhere in the book is such a picture description to be found and it might well be added to a future edition. For all users of electron microscopes, the book will be useful: there is no difficult mathematics and the style is clear and concise.

W. COCHRAN

Device for the stabilization of helium cryostat temperatures

C. J. ADKINS, M.A., Ph.D., Cavendish Laboratory, Cambridge

received 13th February 1961

Abstract. A simple but sensitive method of detecting small changes in the level of an oil manometer is applied to the stabilization of helium cryostat temperatures. At 3°K a stability to better than 10^{-4} deg K is easily obtained.

In a liquid helium cryostat, temperatures over the range $2-4^{\circ}\text{K}$ are conveniently obtained by controlling the rate at

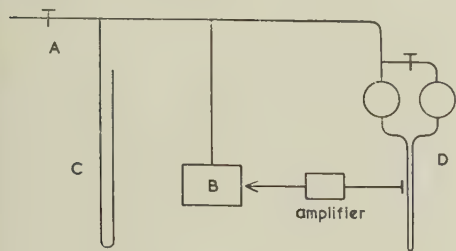


Fig. 1. The arrangement of the helium and control systems. (For explanation, see text.)

which the helium vapour is pumped away. By means of a needle valve between the pump and the helium bath, it is possible to obtain a fine control of the pumping rate, and therefore of the temperature. The maintenance of a constant temperature, however, requires continual adjustment of the balance between the pumping rate and the amount of heat

detected photoelectrically, and the resulting signal is used to control the rate at which power is dissipated in a small heater in the bottom of the helium bath. If the temperature tends to fall, more heat is supplied to the bath, and in this way, the bath temperature is kept very nearly constant.

The oil manometer is made of glass tubing with about 7 mm external diameter. When filled with silicone oil (DC 200), the tube forms a cylindrical lens of a convenient focal length to focus the light from a pea lamp (6 v, 150 mA) placed against the tube, into a sharp line a few millimetres away. If a phototransistor is placed with its sensitive region on this line, it suffers a sharp increase in illumination when the oil meniscus rises.

The associated circuit is shown in Fig. 2. Negative feedback is applied to the phototransistor T_1 to improve the stabilization against temperature changes. The second transistor, T_2 , is biased so that it does not accept the current from the phototransistor until it has reached a certain minimum value. Above this value, the current from the phototransistor is amplified and passed on to a further stage of amplification by T_3 , which acts as an emitter follower to drive the heater in the helium bath. The upper limit to the current which can be delivered to the heater is fixed by the bottoming of the output transistor. In the circuit shown, using a 180 ohm heater element, a maximum of 20 mA can flow. This corresponds to a maximum heater power of about 80 mW, which is adequate for most purposes.

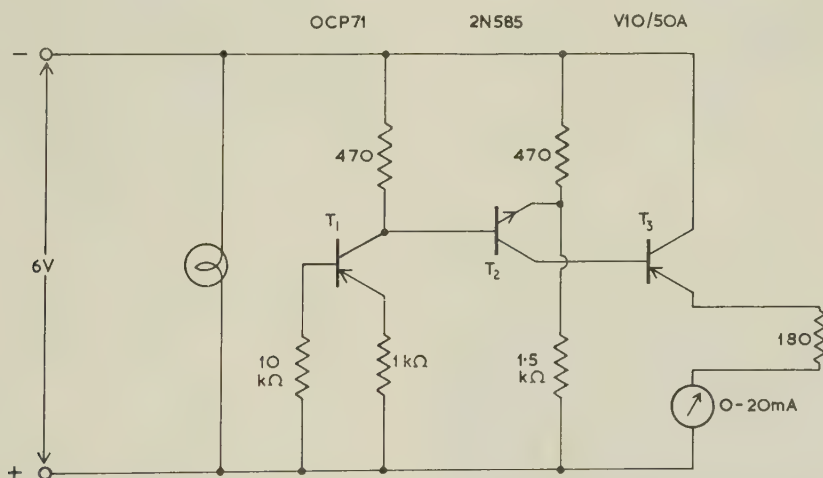


Fig. 2. The current amplifier and limiter. The values of resistors are shown in ohms unless otherwise stated. The types of transistor are given at the top of the diagram.

entering the bath. An arrangement used to achieve this is shown in Fig. 1.

The needle valve A controls the rate at which the helium in B is pumped. The mercury manometer C measures the vapour pressure of the liquid helium, and from this, its temperature can be calculated. To keep the bath at a particular temperature, the tap on the differential oil manometer D is adjusted so that the oil then follows any changes in the vapour pressure of the helium. The changes in the oil level are

detected photoelectrically, and the resulting signal is used to control the rate at which power is dissipated in a small heater in the bottom of the helium bath. If the temperature tends to fall, more heat is supplied to the bath, and in this way, the bath temperature is kept very nearly constant. The oil manometer is made of glass tubing with about 7 mm external diameter. When filled with silicone oil (DC 200), the tube forms a cylindrical lens of a convenient focal length to focus the light from a pea lamp (6 v, 150 mA) placed against the tube, into a sharp line a few millimetres away. If a phototransistor is placed with its sensitive region on this line, it suffers a sharp increase in illumination when the oil meniscus rises. The associated circuit is shown in Fig. 2. Negative feedback is applied to the phototransistor T_1 to improve the stabilization against temperature changes. The second transistor, T_2 , is biased so that it does not accept the current from the phototransistor until it has reached a certain minimum value. Above this value, the current from the phototransistor is amplified and passed on to a further stage of amplification by T_3 , which acts as an emitter follower to drive the heater in the helium bath. The upper limit to the current which can be delivered to the heater is fixed by the bottoming of the output transistor. In the circuit shown, using a 180 ohm heater element, a maximum of 20 mA can flow. This corresponds to a maximum heater power of about 80 mW, which is adequate for most purposes.

A simple volumenometer

by R. G. LOASBY, B.Sc., Ph.D., United Kingdom Atomic Energy Authority, Aldermaston, Berkshire

MS. received 17th February 1961

Abstract. A volumenometer is described which utilizes the linear expansion of an oil-filled metal bellows to measure the volume expansion of solid materials.

Introduction

Expansion measurements on anisotropic materials made with a linear dilatometer suffer from the disadvantage that they may not be representative of the volume changes occurring. In order to overcome this disadvantage a volumenometer has been constructed which measures volume changes directly once the instrument has been calibrated.

The volumenometer

The apparatus (Fig. 1) comprises a lightweight brass bellows which is sealed at one end and serves as the specimen

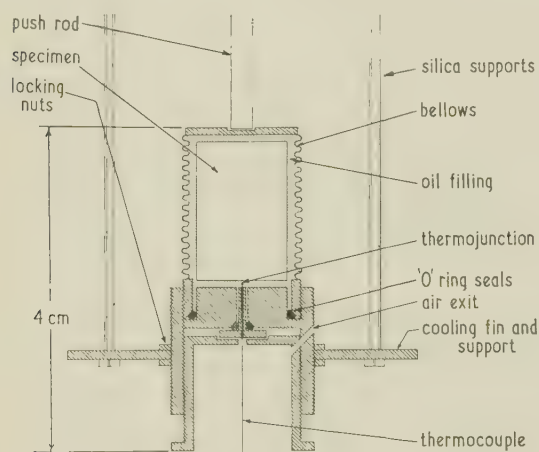


Fig. 1. Volumenometer detail.

container. The interspace between bellows and specimen is filled with a silicone fluid: oil tightness of the assembly is maintained by two 'O' rings on the specimen container and the thermocouple seal in the base of the unit. The 'O' rings are of Viton,* an oil resistant synthetic rubber which will withstand 250°C and the thermocouple is a Philips' 'Thermocoax' chromel-alumel type which is metal sheathed and therefore provides an oil-tight seal into the body of the instrument. The volume expansion of the contents produces a linear expansion of the bellows which is measured with a transducer, the signal from which produces the expansion curve on the chart recorder. To enable the temperature of the apparatus to be rapidly changed a cooling fin is fitted and the thermal capacity minimized.

With the present apparatus equilibrium conditions may be obtained in the 30–60°C temperature range within 45 seconds

of quenching from above 150°C, the low thermal conductivity of the oil being the limiting factor on quenching rate.

Experimental procedure

The volumenometer is first degassed after which it is placed in a vacuum chamber. Whilst under vacuum the chamber is flooded with silicone fluid which has previously been outgassed by heating it under vacuum. Once filled the unit is manipulated in a bath of fluid and only removed when completely assembled.

For anisothermal experiments initial calibration experiments were made using the unit full of oil only, an X recorder being used to obtain the expansion temperature data. Once this has been done the expansion coefficient of specimens may be derived by subtraction, knowing the coefficient for the fluid and apparatus. The sensitivity of the apparatus to specimen volume changes depends on the ratio of specimen to fluid volume contained in the unit. The higher the ratio the greater the response to specimen behaviour. With the present apparatus the contained volume is about 1.5 cm³ of which 1.0 cm³ is specimen. Any increase in this ratio to improve this ratio results in a lowering of the quenching rate obtainable; the size chosen for any particular experiment must therefore be a compromise between these two competing factors.

Experimental results

The unit was devised for following isothermal transformations: no calibration is needed for this application because only relative and not absolute expansions are required. The apparatus has been used for examination of the β - α transformation in plutonium metal and a reaction curve obtained at 60°C is shown in Fig. 2. It has also been used to investigate

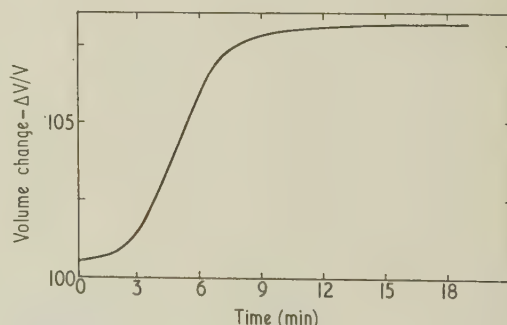


Fig. 2. Plutonium β - α phase change at 60°C.

the variations in the kinetics of the α - β change with thermal cycling: it is particularly useful in this application as specimen distortion has no effect on the measurements and oxidation is limited by the enclosing form of the system.

Acknowledgments

The author is grateful to C. F. Sampson and W. Terry for assistance with the apparatus.

* 'A' EP.101/80 James Walker & Co.

contactless resistivity meter for semiconductors

J. C. BRICE, M.A., and P. MOORE, A.M.Brit.I.R.E., Mullard Research Laboratories, Salfords, Surrey

Received 10th January 1961

The measurement of resistivity provides a convenient estimate of doping levels in semiconductors. This note describes a simple apparatus for the comparative determination of resistivity in the range 10^{-3} to 10 ohm cm, using the eddy-current principle (Hochschild 1954a, b, Young 1955). The method does not require special specimen geometry or surface preparation, it avoids injection and contact potential difficulties often experienced with conventional methods and also lends itself to continuous measurement.

Eddy currents are induced in the specimen by a flat spiral inductor forming part of the tuned circuit of an oscillator working at about 10 Mc/s. Between the inductor and specimen is a copper-fibreglass laminate screen, which acts as a spacer and protects the inductor from abrasion. To avoid induction of eddy currents in it, the copper layer is photo-etched in a comb-shaped area adjacent to the inductor. The inductor consists of 25 turns of 46 s.w.g. wire with an outside diameter of 5.8 mm and is separated from the specimen surface by 0.25 mm.

Figure 1 shows the circuit diagram. The oscillator consists of a cathode follower coupled to a grounded-grid amplifier

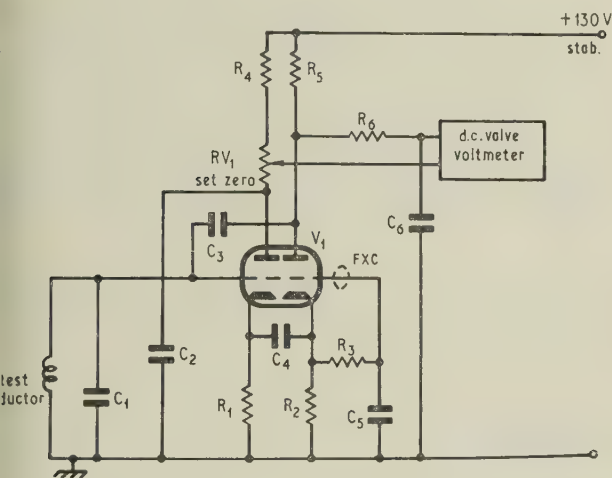


Fig. 1. Circuit diagram.

$R_1 = 180 \Omega$	$C_1 = 100 \text{ pF}$
$R_2 = 680 \Omega$	$C_2 = 1 \text{ nF}$
$R_3 = 1 \text{ M}\Omega$	$C_3 = 33 \text{ pF}$
$R_4 = 2.6 \text{ k}\Omega$	$C_4 = 1 \text{ nF}$
$R_5 = 4.7 \text{ k}\Omega$	$C_5 = 1 \text{ nF}$
$R_6 = 220 \text{ k}\Omega$	$C_6 = 1 \text{ nF}$
$RV_1 = 200 \Omega$	$V_1 = \text{E88CC}$

with zero static bias. In the absence of a specimen, oscillation amplitude is at a maximum, when the second stage mean anode current is minimized by bias developed across the grid capacitor during positive grid-voltage intervals of oscillation. The first stage mean anode current is at a maximum due to the nature of the nonlinear loading imposed by the second stage input impedance. A specimen of appreciable conductivity introduced into the inductor field increases tuned-circuit losses thus decreasing oscillation amplitude.

This causes mean anode current changes in opposite directions in the two stages and the resultant difference in anode voltages is indicated, after filtering, by a Philips GM6010 valve voltmeter. A Ferroxcube bead (Mullard Ltd.) threaded over the second stage grid lead suppresses unwanted modes of oscillation otherwise encountered when tuned circuit losses are high.

Figure 2 gives the resistivity-output voltage characteristic of the apparatus, obtained by comparison with the four-

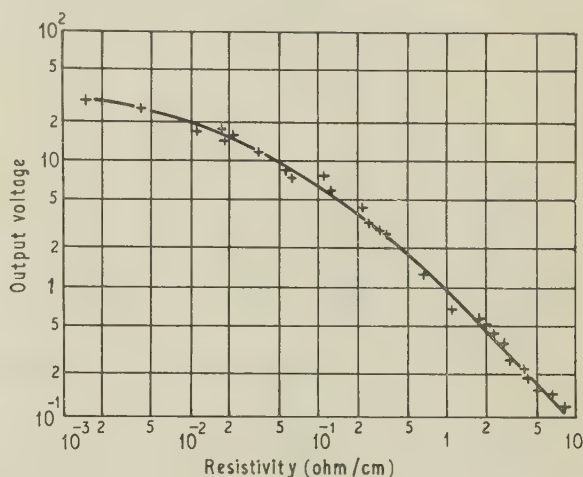


Fig. 2. Calibration curve.

probe method using germanium specimens. The characteristic is independent of specimen geometry, provided that the width of flat specimen surface is greater than the inductor diameter and that the specimen thickness exceeds a dimension X given by the empirical relationship $X \text{ (mm)} = \sqrt{(2\rho)}$ where ρ is the resistivity in ohm cm. Subject to these conditions, the indication is also independent of surface preparation. The upper limit of the measurement range is governed by the short-term stability of the apparatus. The decreasing sensitivity which limits the lower end of the range is largely a function of the complex behaviour of the inductor-specimen combination (Hochschild 1954a, b) since it has been found that the output indication is approximately proportional to the tuned-circuit resistive loading. The results obtained at room temperature using the given calibration curve have a probable deviation of 5% compared with the four-probe method, whilst the reproducibility for any particular specimen is within 2%. Agreement to within 10% has been obtained on samples at liquid nitrogen temperature.

The apparatus has been applied successfully to specimens of germanium, silicon and gallium arsenide.

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- 1954b, *Non-Destr. Test.*, **12**, Sept./Oct., 31.
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Loading device for x-ray cameras

by R. O. A. HALL, United Kingdom Atomic Energy Authority, Harwell, Berkshire

MS. received 6th March 1961

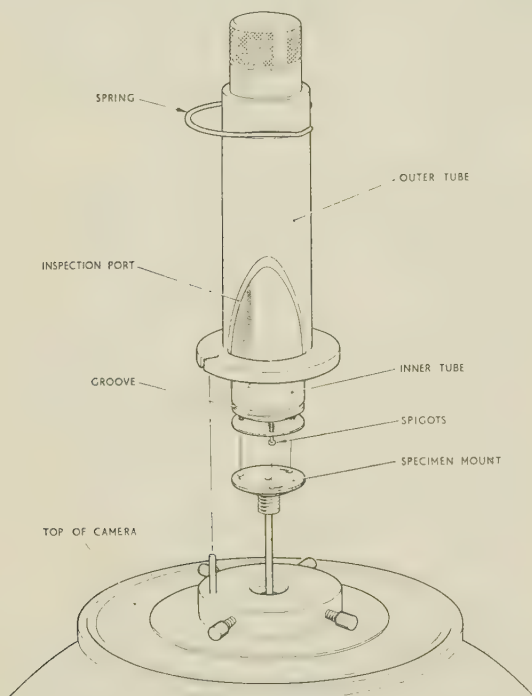
During the recent commissioning of a Unicam type S150 high-temperature x-ray camera, trouble was experienced in the method of loading and unloading the specimens. Several times during the calibration runs the specimen was broken while being removed. The design of the camera was such that it could not be easily modified to alter the specimen

position or specimen holder; the specimens had to be loaded through the top in the standard holder. As the camera was to be used in an open laboratory with α -active materials the normal method of unloading by hand was not acceptable.

A device has been designed for the safe loading and unloading of such materials from the camera; it consists basically of two tubes, one a good sliding fit in the other (see the Figure). The outer tube has an inspection port in the lower end and a spring near the top edge; this spring engages with a groove in the lower edge of the inner tube ensuring that the tube cannot be completely withdrawn without an accident. Three spring-loaded spigots in the bottom of the inner tube engage with three circumferentially elongated holes in the top of the specimen holder. These slots are arranged that as the specimen holder is unscrewed from the camera-centring device the spigots are forced into the narrow part of the slots.

Loading is a simple operation, the specimen holder with complete with specimen is pressed on to the three spigots and rotated anticlockwise; this grips the holder tightly. The inner tube is then withdrawn up inside the outer tube until the tip of the specimen is well inside the outer tube. The base plate of the outer tube is placed on the rotating head of the camera and held firmly in place by the fingers, the specimen being lined up with the centre of the hole in the rotating head, by means of the opening in the outer tube and slowly pushed into the camera. The base plate of the outer tube must be held steady during this operation. The springs on the spigots allow the specimen holder to be screwed up fairly tightly before the spigots disengage from the holder. Unloading is a similar process in reverse.

The author wishes to acknowledge the help and encouragement given by Dr. J. A. Lee and to thank Mr. D. J. Hefferman for assistance in manufacturing the prototype.



Device for the safe loading and unloading of α -active materials from a high-temperature x-ray camera.

Rubber as a sample for proton resonance fluxmeters

by S. J. ROGERS, B.Sc., Admiralty Surface Weapons Establishment, Portsmouth, Hampshire

MS. received 6th March 1961

It has been found that both natural and synthetic rubbers (e.g. those made to British Standards specifications B.S. 1155 and B.S. 2751) form samples suitable for use in proton resonance fluxmeters. Under conditions where the use of liquid samples is precluded, rubber has proved to be a satisfactory substitute. As no container is required for the solid sample the closest coupling between the r.f. coil and sample can be obtained. This is an advantage where small probes are required.

Comparison between glycerol and rubber has been made by substituting one for the other in the same r.f. coil and former. Results show that for all practical purposes the

gyromagnetic ratio and line width of rubber are equal to those of glycerol. The signal amplitudes of rubber and glycerol are roughly in the ratio of 3 to 4.

Since it has only been possible to take samples from a few of the more common rubbers, no proper analysis of variation of signal amplitude with the grade of rubber has been made. Generally speaking, larger signals are obtained from the purer grades.

The effectiveness of natural rubber as a sample material may be attributed to: (a) the relatively large number of hydrogen nuclei per cubic centimetre (approximately equal to that in glycerol); (b) its liquid-like behaviour (Slichter, 1960).

59). The large thermal agitation of the lattice even at room temperature would account for a short spin-lattice relaxation time.

Some experiments have been carried out to compare signal amplitudes of rubber with those of liquids over a temperature range 20 to 60°C. The characteristic for rubber is similar to those of glycerol and liquid paraffin. All samples, 0.1 in. long and 0.04 in. diameter, made in pieces of elastic band, have been used to make magnetic field plots in the air-gaps of magnets.

Measurements of magnetic field strength in the range 500–20 000 oersteds have been made using rubber as the sample material.

In magnets where the field in the gap is very non-uniform but has circular symmetry about the axis, it may be feasible to use a ring-shaped sample of rubber in a toroidal r.f. coil. This method would allow an increase in sample volume without incurring an undesirable field gradient over the sample.

SLICHTER, W. P., 1959, *J. Chem. Educ.*, **36**, 185.

NOTES AND NEWS

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep her informed of their new or improved products. The Institute of Physics and The Physical Society assumes no responsibility for the statements given below; information for these has been taken from literature supplied.

Electrosensor voltmeter. Halex, Inc., 310 East Imperial Highway, El Segundo, California, U.S.A. (U.K. Concessionaires: Scientific Furnishings Ltd., Poynton, Cheshire.)

The model 301 E Electrosensor Voltmeter is a precision high impedance unity gain follower-amplifier with effective input resistance greater than $10^{17} \Omega$, and effective input capacitance less than 0.01 pF. Low and high impedance output terminals are provided with output impedance less than 0.2Ω and less than 500Ω respectively.

Eight stages of amplification are used, including a floating electrometer amplifier but without either vibrators or choppers. Essentially the unit consists of three unity-gain amplifiers completely surrounded by three distinct screens, the earth for the inner amplifiers serving as the screen for the succeeding amplifiers. Each of the three screens is connected to one of three Teflon insulated guard shields concentrically located between a centre input conductor and an external earth shield. The three guard shields are driven from the amplifiers in the instrument at voltages very nearly identical to the input signal on the input conductor. The result is that the effective output impedance is raised above that of the Teflon insulation, and even above that of the free space surrounding the instrument. The multiple shielding also prevents stray pick-up. An output meter is provided, with accuracy to within 2%

of full-scale deflection. A switch selects from eleven ranges with full-scale values from $\pm 1 \text{ v}$ to $\pm 250 \text{ v}$ d.c., or 500 v peak-to-peak for low frequency a.c. Frequencies up to 1 kc/s can be accepted at low amplitudes from a low impedance source. The meter switching does not affect the input resistance, the output from the terminals, or the gain of the individual amplifiers. After a two hour warming-up period the drift is less than 2 mv per hour. For the low impedance output the d.c. following accuracy is to 0.02% and the d.c. proportionality factor 0.9995; the corresponding figures for the high impedance output are 0.001% and 0.99997 respectively.

The instrument measures only 10 in. $\times$ 7 in. $\times$ 4 in. A large number of accessories is available for such purposes as: the integration of analogue currents; the measurement of resistances with an accuracy to 0.002% of a known standard resistance and direct readings up to $10^{17} \Omega$; high gain d.c. amplification with an accuracy to 0.05% up to a gain of 100; current regulation down to 10^{-13} A ; and static detection up to $\pm 250 \text{ kv}$.

Electromagnetic counters. Counting Instruments Ltd., 5 Elstree Way, Boreham Wood, Herts.

The series 400 counters are available with four figures and either mechanical or electrical reset. They have wheels $\frac{3}{4}$ in. diameter and white figures, $\frac{7}{32}$ in. high, which are sunk into the figure band for greater readability. Actual tests indicate that a life between 200 and 300 million counts can be expected at a counting rate of 25 per second. The counters are designed to meet the requirement for compact banks and are built in a mazak die-cast case measuring $2\frac{3}{4}$ in. wide, $2\frac{3}{16}$ in. high and $2\frac{5}{8}$ in. long.

Universal electrophoresis apparatus. Shandon Scientific Co. Ltd., 6 Cromwell Place, London, S.W.7.

This universal electrophoresis apparatus is an improved model which was designed in conjunction with Dr. J. Kohn of Queen Mary's Hospital, Roehampton.

It is a versatile piece of equipment which may be used for a broad range of routine and research work on cellulose acetate techniques.

The equipment is suitable for large scale, small scale or micro-electrophoresis. The makers also claim that as well as being suitable for use with filter paper, agar gel or starch, it is the most efficient, easily operated and economic apparatus available for work with cellulose-acetate membrane filters.

Cellulose-acetate techniques

Using this apparatus, cellulose-acetate techniques offer the following advantages:

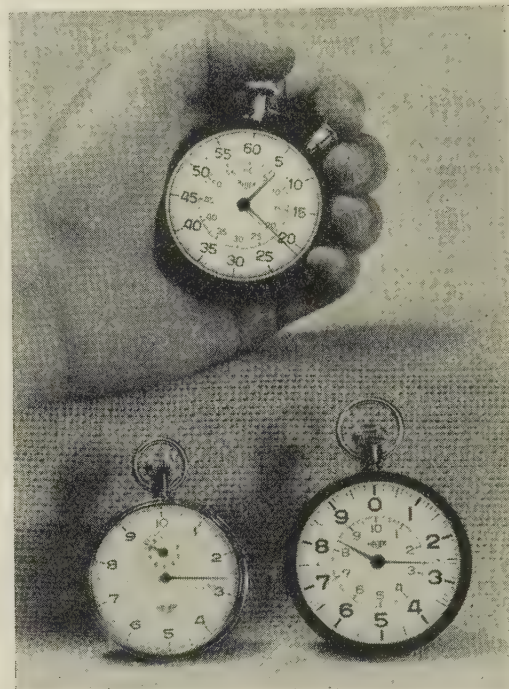
- (1) Adsorption is very low and there is practically no 'tailing'.
- (2) Separation is sharp (particularly the α_1 fraction from the albumin in serum) and the background is colourless, greatly improving the accuracy of qualitative analysis.
- (3) The material is homogeneous, microporous and chemically relatively pure. There are no hemicelluloses or lignins present and heavy metal traces are very low. This may be important for analytical purposes.
- (4) Separation is rapid ($1\frac{1}{2}$ –2 hours using the small scale technique). The whole procedure, including staining and drying, can be completed in $2\frac{1}{2}$ hours.
- (5) Only a small sample is necessary (with nigrosine staining even 0.0001 ml with a protein content down to $5\text{ }\mu\text{g}$ can produce a clear pattern).
- (6) The strips can be made completely transparent to both u.v. and visible light by immersion in a clearing fluid.
- (7) The medium can be used on its own or in combination with agar gel for immuno-diffusion techniques.
- (8) It is eminently suitable for electrophoretic and immuno-diffusion studies of isotope-labelled protein.
- (9) It can easily be cut into small sections after separation of the proteins—a valuable feature in immunological and enzyme studies.
- (10) Some fractions not normally seen on filter paper can often be clearly demonstrated on cellulose acetate.
- (11) Glycoprotein staining is invariably successful and globulin fractions containing glycoprotein are discrete and well separated.
- (12) A recently introduced staining technique permits the demonstration of lipoproteins.
- (13) Haematological departments will be interested in the use of cellulose acetate in the newly devised FIGLU test for folic acid deficiency, for which the Shandon apparatus is well adapted.

Primary resistance standard. Julie Research Laboratories Inc., 603 West 130th Street, New York, U.S.A.

The Model MRS-105 multiple resistance standard provides five reference values of 100, 1000, 10000, 100000 and 10^6 ohms. Absolute accuracy is claimed to be 0.003% at 100 ohms and 0.0015% at other values, with a long term stability better than 0.0015% per annum. Thermally induced transient effects, e.g. self-heating, Seebeck and Peltier effects, are less than 0.005% at rated current. The resistance elements are oil-immersed and hermetically sealed in a metal case about 9 in. $\times$ 3 in. $\times$ 1 in.

Stopwatch with central minute register. E. D. Heuer and Co. S.A., Biel-Bienne, Switzerland. (Distributors: Baume and Co. Ltd., 50 Hatton Garden, E.C.1.)

The stopwatch capacity and legibility have been considerably increased due to design changes which permit minutes to be indicated on a large central dial rather than on the small conventional off-centre dial. Up to 60 minutes of elapsed time may now be registered rather than the usual 30 minutes. Both the dial and the lettering are 85% to 100% larger than those on previous designs. The improvement has already been incorporated in almost the complete range of Heuer stopwatches.



By using the central shaft for the minute as well as the sweep second hand Ed. Heuer and Co. S.A. have doubled the capacity and increased the legibility of stopwatches.

The conventional styling (left) is compared with the new styling (right). The upper timer illustrates the doubled capacity of 60 minutes in the register dial.

As well as having a central register the watches have been increased by $\frac{1}{4}$ inch in diameter for better legibility and a more comfortable fit in the hand. The makers claim perfect synchronization in all watch orientations and on both halves of the register.

Air filter. Gelman Instrument Co., Chelsea, Michigan.

The Gelman Instrument Company in co-operation with Delbag Luftfilter of Berlin have developed a new air filter.

This filter has been demonstrated to be 99.998% efficient using test aerosols of 0.3 micron in diameter and to be capable of retaining high dust loadings without significant change in the resistance of the filter.

The filter is made of micro fibres of polystyrene which are laid down in a continuous belt. As a result of this the filter is able to accumulate up to ten times more dust than previously developed filters, for the same change in pressure drop.

It is anticipated that the new material will be used in sampling, industrial filtration and in special high efficiency filtering units.

idual gas analyser. Consolidated Electrodynamics Corporation, Pasadena, California, U.S.A.

This instrument is designed for the continuous analysis of dual gases in vacuum systems and is effectively a mass spectrometer with a mass range of 2 to 80. Resolving power is sufficient to separate adjacent peaks (with valleys 1% of peak height) up to mass 20, and sensitivity is such as to allow the analysis of gases having partial pressures in the range 10^{-4} to 10^{-9} torr. The equipment comprises a mass analyser, which is bakeable to 450°C , a d.c. amplifier and a control unit. A dial on the latter is engraved with mass numbers and rotates automatically during the scanning process, but can be operated manually for selective analysis of selected peaks. The scanning can be set to start and stop at any point in the spectrum and an accessory is available to automate and control the scan of a preselected series of masses. With no attenuation noise is below 1% of full scale, while drift is below 1% of full scale per hour and not more than 5% per day. Normal power input is 105–125 volts, 50 c/s, but a 50 c/s factory conversion kit is available. A 10 mv or 100 mv potentiometric recorder can be operated directly from terminals provided.

F. Spectrum Analyser. Fenlow Electronics Ltd., Springfield Lane, Weybridge, Surrey.

This instrument, which was designed originally for aircraft studies, is of the constant bandwidth type. The frequency range of 0.3 to 1050 c/s is covered in five bands, while the bandwidth is adjustable from 0.06 to 37.5 c/s in five steps in a 5:1 ratio. A built-in meter displays the power of the random waveform in the pass band to which the instrument is set and facilities are provided to take out the signal after the meter for recording purposes. A heterodyne system is employed with low-pass output filters and two quadrature channels to prevent ambiguities due to phase synchronization of almost periodic inputs. Accurate square law thermocouples are used to measure the power, these being followed by a smoothing unit with controllable smoothing times. The instrument is housed in a cabinet measuring 20 in. $\times$ 21 in. $\times$ 10 in. overall, the controls and meter being mounted on a top panel. Typical applications suggested by the makers include the studies of motor vehicle suspensions, railway carriage lurching, wind effects on building structure, mounts for heavy machinery and the study of radio fading.

Hygro-Robots. British Sarozal Ltd., 22 Berners Street, London, W.1.

Hygro-Robots remove moisture from the air without unduly heating or lowering the ambient temperature unless this should be required. They can be used either for quick drying or for providing an automatic humidity control.

The Hygro-Robots can operate within a temperature range of 40°C to -10°C and can either be preset for automatically controlling relative humidity between 30–100% or used to keep a constant humidity of 30–50% in rooms of up to 5000 ft³.

The system works by cooling the room air, drawn in by a fan, to below dew point. The water can then be removed. An air circulation of up to 63 000 ft³/h can be attained with the larger capacity models.

The machines are easily portable and as they have a con-

sumption of only 680 w it is possible to plug them into any convenient 5 A, 240 v point.

Precision sound level meter. B. & K. Laboratories Ltd., 4 Tilney Street, Park Lane, London W.1.

The Bruel and Kjaer type 2203 instrument is transistorized, portable and battery-operated and is built to fulfil the proposed IEC standards for precision sound level meters. Equipped with a precision condenser microphone (B. & K. type 4131) the instrument gives a direct scale reading from 22 to 134 db to ± 1 db and a linear frequency characteristic from 20 c/s to 15 kc/s. An overall amplification of 110 db gives full deflection on the meter for an input voltage of $10\ \mu\text{V}$, and by applying extensive negative feedback throughout, stable operation of the amplifier is ensured. A built-in stabilized control generator gives a ready check on the amplification. Between the first and second stages of the amplifier the three IEC weighting networks for precision sound level meters are included. The rectifier circuit for the meter is of the quasi-r.m.s. type to fulfil the IEC standard requirements.

The meter is versatile, in that it can be rapidly converted into a frequency analyser by the connection of external 1/3 and 1/1 octave filters, and when a permanent record of the measurements undertaken is required, a level recorder can be connected to its output. By substituting the microphone cartridge with an adaptor (input adaptor JJ2612) it can be converted to a voltage and vibration amplifier, and by connecting an accelerometer to the input, vibration measurements can readily be made. To facilitate the taking of measurements in dim and badly lit places the meter scale can be lit, and when in operation an intermittent pilot light periodically flashes, indicating that the power supply is on. The instrument can be supplied with a solid leather carrying case.

Electronic micromanometer. Gelman Instrument Co., 106 North Main Street, Chelsea, Michigan, U.S.A. In Europe: B.I.R.N.s.a. 1026–1048 Chaussee de Louvain, Brussels 14, Belgium.

This is a sensitive pressure measuring device capable of measuring differential gas pressures of 0.004 in. water gauge full scale. The scale is linear so that pressures down to ± 0.00016 in. can be read.

The measuring head consists of two symmetrically arranged cavities separated by a metal diaphragm, each with a fixed electrode. These form two condensers which are part of the tuning capacities of two tuned circuits, both of which are equally coupled to an r.f. oscillator. Movement of the diaphragm causes a variation in the capacitance between it and each adjacent electrode. This difference is measured and displayed on a panel meter which is calibrated in pressure units. The pressures to be measured are connected to the measuring head via two pipe fittings on the front panel; tubes up to 20 ft in length may be used with no loss of accuracy. Micromanometers are available to give full scale readings of ± 0.004 in. water gauge to ± 10 in. water gauge. Static working pressures up to 1000 lb/in² and differential overloads up to ten times full scale pressure can be applied without damage.

The sensitive element will respond to sinewave pressure variations of 200 c/s or more. A jack is provided to allow an external recorder to be used, the output resistance is

500 Ω with a switch which increases the output time constant to 0.3 s.

Very high pressure airhydropump. Charles S. Madan & Co. Ltd., Broadheath, Altrincham.

Pressures up to 100 000 lb/in² are produced from compressed air at 80–100 lb/in² by this reciprocating pump, which has an output of just over 6 in³/min at 10 000 lb/in² and just under 2 in³/min at 90 000 lb/in². The pressure is fully controlled by means of an air control valve which can be operated by hand to raise the pressure gradually, or can be preset to produce the required pressure. When the air is turned on the pump reciprocates until this pressure is reached, when it rests in a state of balance, the pressure being maintained indefinitely without consuming any air unless there is a leak in the item under test.

The pump can be mounted in a steel safety cabinet with a separate compartment for the item under test and with doors which are electrically operated to prevent opening while the system is under pressure. All controls are outside and the protected pressure gauge is viewed through mirrors. A range of control valves, pressure release valves, elbows, tees and couplings in heat-treated and normalized steel have been designed for use with the pump and are tested to 120 000 lb/in². The Madan high pressure pipe connection has proved to be satisfactory up to 132 000 lb/in² and can be made and broken repeatedly.

Gamma flow detector. Nuclear Enterprises (G.B.) Ltd., Bankhead Medway, Sighthill, Edinburgh 11.

The increasing use of flow methods in radiation detection has led to the development of a special flow counter suitable for continuous monitoring of gamma activity in liquids and gases. The NE 813 detector consists of an 8 ft length of 1.3 mm bore PTFE tubing coiled on a 1½ in. diameter rod of plastic phosphor NE 102, and inserted in a 5 in. diameter × 5 in. high well-type unit of plastic phosphor NE 102.

The detector is suitable for the monitoring of effluents from ion exchange columns, for monitoring of activity of isotopes in aqueous or organic media, and for the analysis of activity in process streams. This unit is of particular value in radiation detection of biological fluids in medical and biochemical studies, and may also be used for the measurement of gamma activity of liquids in static systems.

The NE 813 detector is supplied with an efficient reflector and can be mounted directly on any standard 5 in. diameter photomultiplier using silicone fluid as a coupling medium. The PTFE tubing employed is chemically inert, insoluble in all solvents at ordinary temperatures and easily cleaned.

Notes and Comments

Notes on the preparation of papers

We will, in future, be publishing in each issue of *Journal* notes on the preparation of papers to be submitted for publication. These instructions will give the main points to be considered. Full details are available in the *Institute and Society's 'Notes for Authors'*, obtainable free of charge from the Editorial Office, 1 Lowther Gardens, Prince Consort Road, London, S.W.7.

Authors should submit two copies of their manuscript typed in double spacing on one side of the paper, each with a set of small copies or prints of the diagrams attached. There should also be two extra copies of the title and abstract and a set of fair copies of the diagrams drawn in Indian ink with the lettering in soft or blue pencil. An important point to notice is the style of references which should be used. The text references should be made by giving the name of the author and the year of publication, e.g. (Jones 1964) and details should be given in the list at the end where references are arranged in alphabetical order of author names.

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British Journal of Applied Physics

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NOTES AND COMMENTS
New books Notes and comments

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Non-destructive method of gauging electrodeposited nickel layers

P. M. REYNOLDS, B.Sc., Ph.D., The British Non-Ferrous Metals Research Association, Euston Street, London, N.W.1

Received 27th January 1961, in revised form 17th April 1961

Abstract

A instrument for gauging electrodeposited nickel layers within the thickness range 0.2 mil to at least 1.5 mil is described. It utilizes the local thermal e.m.f.s set up when a heated metal probe is brought into contact with the coating. The final design, now in commercial use, is of high stability effected by minimizing temperature drift in the probe and by selecting materials of appropriate thermoelectric properties.

The influence of the differing thermoelectric properties of various commercial nickel deposits upon the accuracy of measurement has been evaluated. Extensive industrial trials are reported. With substrates of steel, copper-plated steel and copper-plated zinc alloy, amongst 1400 individual measurements of nickel thickness about 90% were within ± 0.1 mil.

Introduction

ELECTRODEPOSITED nickel of thickness 0.3 to 2.0 mil with a superficial layer of chromium (0.01 to 0.03 mil) is used for decorative plating. The basis metal is usually brass, steel or zinc-alloy die-casting, but on steel or on the nickel layer may be preceded by a copper undercoat (0.1 to 1.0 mil). The corrosion resistance of these composite layers largely depends upon the nickel thickness, and minimum local nickel thicknesses are specified (British Standard 1224, 1953) for each basis metal and condition of service. This had led to a demand for a rapid, inexpensive and non-destructive method of measuring the local nickel thickness within an accuracy ± 0.1 mil on complex surfaces at any point which can be touched by a ball of 1 in. diameter. Existing methods of gauging nickel include magnetic (Brenner 1937, 1938), eddy-current (Brodell and Brenner 1957), electron beam (Kriegler and Schumacher 1960) and x-ray fluorescence (Goodwin and Winchester 1959) techniques. Each has limitations, arising from the variable properties of electrodeposited nickel, changes of calibration with specimen curvature, or from the cost and size of the equipment. In the magnetic method (Brenner 1937, 1938), the normal attractive force between a small hemispherical-ended magnet and the nickel or basis metal is determined. Nickel deposited under different conditions has different magnetic permeability, but by standardizing against similar test pieces prepared from the same bath as the specimens an accuracy to $\pm 10\%$ is obtained over the range 0.1 to 1.0 mil. This accuracy is affected by a thin chromium layer (0.01 mil), but if the basis metal is steel, copper undercoats introduce serious errors, i.e. a copper layer is equivalent to 2-4 times its own thickness of nickel (Brenner 1938). Eddy-current methods (Brodell and Brenner 1957) are more sensitive than the magnetic method to variations in the magnetic permeability

of nickel, which arise from changes in the stress in the deposit. Further errors arise if the curvatures of the calibration standards and unknown specimens differ, and eddy-current instruments cannot be used conveniently on specimens of varying curvature. Although x-ray fluorescence methods (Kriegler and Schumacher 1960, Goodwin and Winchester 1959) yield higher accuracy (± 0.01 mil), the cumbersome and expensive equipment is unsuitable for routine use in a plating shop.

The present paper describes a thermoelectric instrument for gauging nickel deposits. Highly localized, non-destructive measurements can be made on curved surfaces, and readings can be taken at 5 second intervals. Although the thermoelectric properties of nickel deposits prepared under different conditions vary, industrial trials upon components from automatic plating baths have shown that within the thickness range 0.1 to 1.5 mil, the accuracy of this instrument is ± 0.1 mil for nickel on steel and nickel on copper on zinc and ± 0.15 mil for nickel on copper on steel. This instrument is essentially for industrial control; it is not suitable for gauging nickel deposits of unknown origin.

A laboratory version of this gauge was described by Heath (1955), but due to a serious drift in calibration when readings were taken too rapidly, it proved unsuitable for routine industrial use. To eliminate this drift it proved necessary to study the principles of probe design more closely. To assess the importance of variations in the thermoelectric properties of nickel a considerable number of commercially plated components were examined, and extensive industrial trials of the redesigned instrument were conducted.

Principle and design of the thermoelectric gauge

The arrangement of the hot probe and measuring circuit is shown schematically in Fig. 1. An electrically heated copper block terminates in an $\frac{1}{8}$ in. diameter hemispherical tip. When this tip is pressed against a plated component a highly localized temperature distribution is established around the area of contact. If the plating and basis metal differ adequately in thermoelectric power (about $20 \mu\text{V deg}^{-1}\text{C}$) and the plating thickness is less than 2.0 mil, the thermal e.m.f. generated at the plating-basis metal interface C varies significantly with plating thickness. Additional thermal e.m.f.s arise at the metallic junctions A and B, but for a given plating and basis metal these are found to be substantially independent of plating thickness. The total e.m.f. generated between the hot probe and a cold part of the specimen therefore varies with plating thickness, and the instrument can be calibrated against microsectional or other standards.

The theoretical heat flow into the workpiece has been discussed by Heath (1955), who showed that if the contact area

is infinitely small a steady temperature distribution is established within 0.01 s. A considerable fall of temperature then occurs within 1.0 mil of the point of contact, but the heat losses from the probe during contact produce a negligible change in the probe temperature. In practice, with a

the stability of calibration depends upon all the thermojunctions in the measuring circuit, i.e. the stability varies with the materials of the hot probe, the probe tip and specimens.

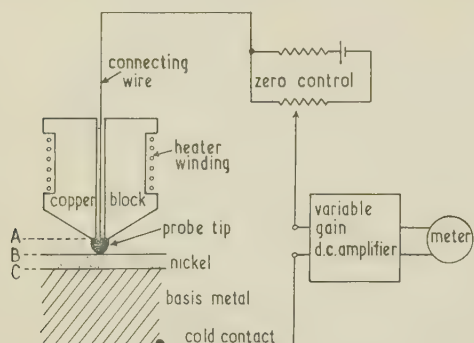


Fig. 1. Schematic diagram of hot probe and measuring circuit.

finite area of contact a quasi-steady state is reached within 2 s, and the heat loss from the probe tends to cause a drift in calibration.

Since the probe signal is not necessarily zero for the minimum nickel thickness to be measured, a steady d.c. signal is injected to allow the total output to be zeroed. The total signal is then fed into a high-stability d.c. amplifier (stability $\pm 5 \mu\text{V}$ input). This amplifier, the zero control, and the constant current supply for the heater were incorporated in a commercial unit developed for the purpose by Nash and Thompson Ltd.

Figure 2 gives a simplified diagram of a probe. The heated copper block H is fixed to a nylon sliding bearing N_1 and central copper tube T. This assembly slides freely in an outer casing which includes a second nylon bearing N_2 . When the probe tip is pressed against a specimen it recesses into the case, releasing a precompressed helical spring S which gives a constant contact load of approximately 2½ lb.

Effect of temperature and materials of probe tip

The sensitivity of the thermoelectric method depends only upon the probe temperature and the difference in the thermoelectric properties of the coating and basis metal. In contrast,

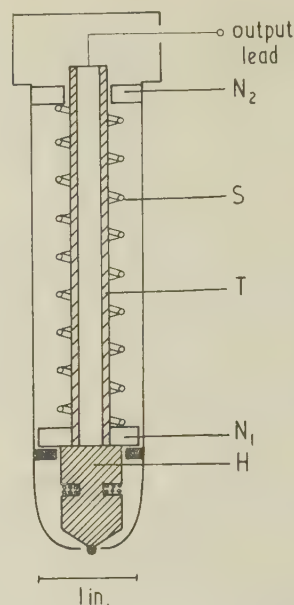


Fig. 2. General assembly of probe.

Figure 3 shows calibration curves for nickel on steel obtained with two different probes with the copper block maintained at temperatures 100, 125 and 150° C. The probes were identical except for the materials of the probe tip which were (i) solid nickel (nickel connecting wire to tip), (ii) solid mild steel (iron connecting wire to tip). With a solid nickel tip junctions A and B (Fig. 1) are eliminated, and the calibration curves show the variation of the thermal e.m.f. at the nickel-steel interface with temperature and nickel thickness. A mild steel tip gives zero output for zero nickel thickness, but with a finite nickel thickness the e.m.f.s at junctions B and C oppose. Although at a given operating temperature the absolute value of the signals differ due to changes in junction B, the sensitivity of these probes to changes in nickel thickness is the same. But junction

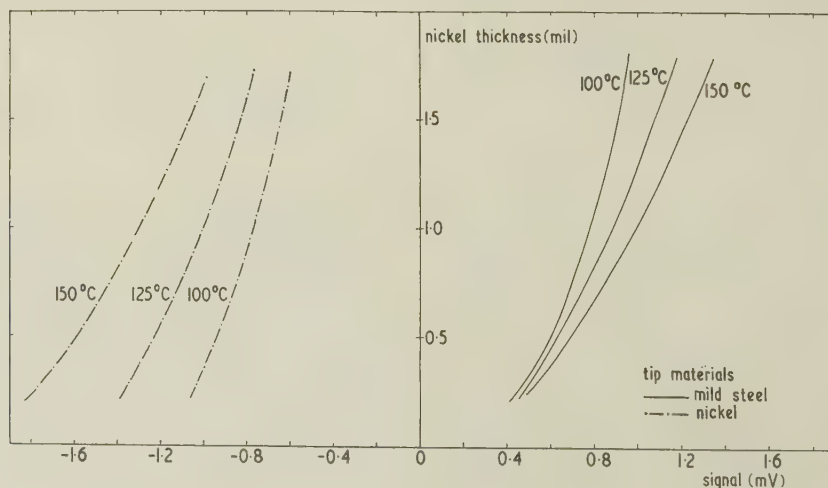


Fig. 3. Nickel on steel: calibration curves for different probes at fixed temperatures.

also A) strongly affects the change in calibration due to a given change in probe temperature. Since heat flows into the specimen during contact some change in the probe operating temperature is inevitable. Fig. 4 shows the temperature changes which occur in a probe and copper block during and after contact with a specimen. These temperatures were measured by inserting fine thermocouples in a probe. When contact ceases the probe

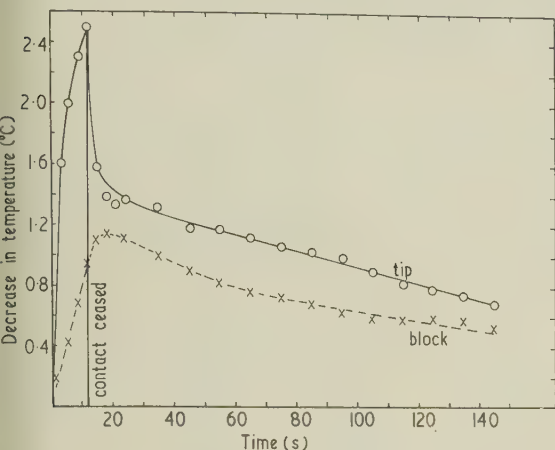


Fig. 4. Decrease in temperature of probe tip and copper block; 12 s contact.

initially recovers by drawing heat from the copper block, thereafter the temperature recovers slowly. If insufficient time elapses between successive applications of the probe, these small temperature changes accumulate, the effective operating temperature is reduced, and the calibration drifts. For this reason an accuracy to ± 0.1 mil was maintained when earlier probe designs were used for rapid routine measurements under industrial conditions. Since the temperature changes occurring at the probe tip are rapid, direct control of the probe temperature was possible. Instead, this drift of calibration was minimized by careful probe design.

Probe load

Theoretically (Bowden and Tabor 1939) the area of contact with the specimen is directly proportional to the probe load. To minimize heat losses during contact the lowest load consistent with reproducible contact is used. It was found that small changes in probe load altered the calibration of the instrument, the sensitivity was not significantly altered except that for coatings less than 0.1 mil the sensitivity was lower for lower loads). The minimum load for reproducible electrical and thermal contact was found to be $2\frac{1}{2}$ lb. Within the range $2\frac{1}{2}$ – $4\frac{1}{2}$ lb the cooling of the probe tip during contact is directly proportional to the load.

Mass of copper block and heater position

The temperature changes in the probe due to heat losses during contact depend upon the thermal capacity of the copper block. But there are two contrary effects; if the thermal capacity is increased the temperature change during contact is reduced, but the time taken for the electrical heater to restore the temperature when contact ceases is increased. To investigate the effect of the mass of the copper block and position of the electrical heater, three blocks of different design were tested. Each block had diameter $\frac{3}{4}$ in. and a

pancake-shaped heater similar to that shown in Fig. 2. The distance between the contact area of the probe tip and the base of the conical taper was also identical, being $\frac{1}{4}$ in. In blocks Nos. 1 and 2 the heater was placed $\frac{3}{8}$ in. from the tip contact, but the mass and overall length of these blocks differed, as shown by Table 1. Blocks Nos. 1 and 3 were identical except for the position of the heater, which in block No. 3 was placed $\frac{1}{2}$ in. from the probe tip.

To exaggerate conduction losses the probe tips and specimen were solid copper. Temperature measurements were made close to the probe tip, and after 100 applications of the probe, each with 3 second contact and 7 second intervals, the decrease in probe operating temperature was noted. This, together with the time for each block to recover 50% of the temperature change is shown in Table 1.

Table 1. Effect of probe mass

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	60.2	$1\frac{1}{4}$	$\frac{3}{8}$	4.0	149	31	15
2	14.0	$\frac{3}{8}$	$\frac{3}{8}$	2.7	149	50	5
3	62.1	$1\frac{1}{4}$	$\frac{1}{2}$	4.1	149	27	16

(1) Model no.; (2) mass (g); (3) overall length (in.); (4) distance of heater from contact area (in.); (5) heater power (w); (6) initial temperature ($^{\circ}$ C); (7) temperature decrease (deg C); (8) 50% recovery time (min.).

Due to the decrease in surface area, block No. 2 required less heater power to maintain the same initial temperature. These results show that to minimize temperature changes the mass of the copper block should be as large as possible. Comparing results for blocks Nos. 1 and 3 it is seen that there is a slight advantage in placing the heater away from the probe tip.

In practice, to examine re-entrant curves of $\frac{1}{2}$ in. radius, the outer case of the probe must terminate in a hemisphere of 1 in. diameter. This restricted the mass of the copper block which could be accommodated to 36 g.

Material of probe tip

Closer study of Fig. 3 shows that if the probe output signal is positive any cooling of the probe causes an apparent decrease in nickel thickness, whereas with a negative output the apparent thickness increases. This suggested that the drift in calibration due to a given reduction in probe operating temperature could be minimized by choosing the material of the probe tip to obtain zero probe output within the range of nickel thicknesses to be measured. To test this hypothesis a change in tip material was simulated by inserting an additional thermojunction in the probe tip, as shown by Fig. 5. Adjusting potentiometer S the signal for 1.0 mil nickel on

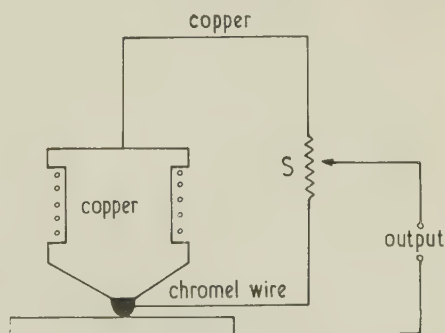


Fig. 5. Circuit with temperature-variable back e.m.f.

steel was reduced to zero. The instrument was then calibrated for nickel on steel, allowing sufficient time between each reading for the probe to stabilize. Next the probe was placed upon a specimen (not otherwise used) for 10 minutes and a calibration curve rapidly replotted before the probe recovered. (This procedure produced a cooling effect equivalent to 200 successive applications of the probe each with 3 second contact and 7 second recovery time.) For comparison this test was repeated with the thermojunction removed and the signal zeroed from a steady back e.m.f. derived from a battery. The corresponding calibration curves are shown in Fig. 6. The additional thermojunction considerably reduced the drift in calibration, indicating that drift of calibration could be reduced by a suitable selection of the tip material.

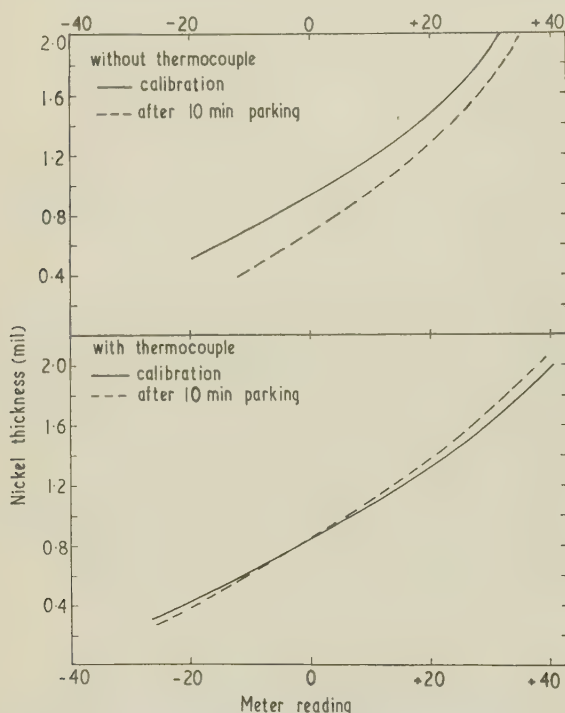


Fig. 6. Effect of thermocouple compensation.

The choice of tip materials was restricted by the need for resistance to wear and corrosion, and the demand for an accurately hemispherical profile. It was found that a hardened carbon-chromium steel (EN 31) had the required thermoelectric properties and could be obtained as hemispherical-ended needle rollers (diameter 2 mm) with closely controlled profile. These needle rollers were press fitted into an undersize hole in the probe body.

Since the stability of a probe depends upon all the thermojunctions present in the measuring circuit, the material of the probe tip should, for optimum performance, be chosen in accordance with the plating and the basis metal. With the carbon-chromium steel tip the error in calibration after 10 minutes contact with a specimen was less than -0.06 mil for nickel on steel within the thickness range 0.5 to 2.0 mil. A higher drift of calibration occurred with nickel on brass, being -0.12 mil for the range 0.2 to 0.8 mil. With specimens of nickel on copper on zinc within the range 0.2 to 2.0 mil of nickel, the drift in calibration was within -0.1 mil, which, in all cases, appeared to be adequate. This was subsequently confirmed by industrial trials.

Final probe design

The details of the probe finally used in the industrial trials were as follows:

Material of probe tip: carbon-chromium steel
(BS 970: EN31).

Diameter of probe tip: 2 mm.

Mass of copper block: 36 g.

Operating temperature: 150°C .

Probe load: $2\frac{1}{2}$ lb.

Hardness of probe tip: Approx. 850 V.P.N.

Probe life

The above probe design was life tested for 100 000 applications. Nickel on steel calibration curves taken during the test agreed to within ± 0.1 mil, which is the normal long term stability of the probe and associated circuits. The flattening of the probe tip gradually increased the standard deviation in results, as shown by Table 2.

Table 2. Effect of probe wear on reproducibility

Thickness of nickel on steel (mil)	Initial	Standard deviation (mil) After 30 000 applications	After 100 000 applications
0.5	0.032	0.036	0.046
1.0	0.028	0.039	0.050
1.5	0.059	0.061	0.072
2.0	0.038	0.062	0.050

Calibration and accuracy

Nickel deposits from different plating baths differ in their electric properties. When commercially plated nickel steel components prepared from different baths and various proprietary nickel solutions were examined, apparent nickel thicknesses determined from a mean calibration curve were in error by ± 0.2 mil. Components prepared from the same proprietary nickel solution, but in different baths showed better correlation; but specimens from the same bath yielded a consistent calibration curve. Similar differences were

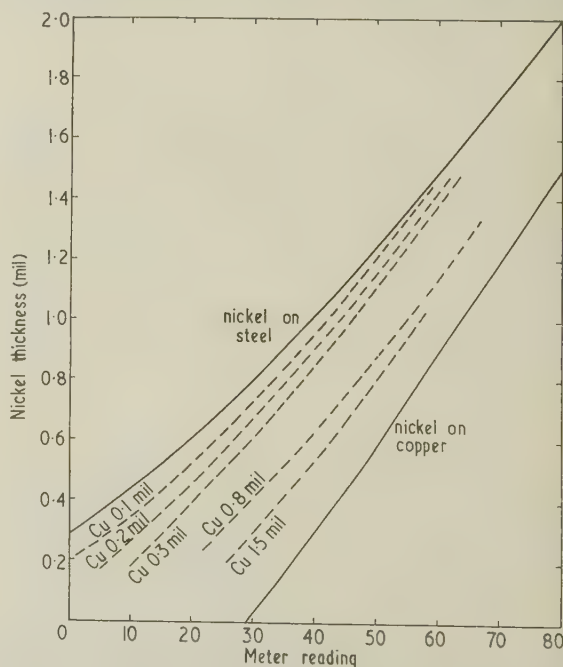


Fig. 7. Calibration curves for nickel on copper on steel deposits. (Copper deposited from cyanide solution.)

tained with nickel on brass, and nickel on copper on zinc specimens. It is therefore essential that the instrument could be calibrated against test pieces prepared from the same plating bath as the specimens, otherwise systematic errors up to 0.4 mil can arise. The method is clearly suitable for gauging nickel deposits of unknown origin. Despite this variation in the thermoelectric properties of nickel deposits, it was found that the shape of calibration curves for each proprietary nickel on any given basis metal is similar. For example, calibration curves for different proprietary nickel deposits on steel could be made to coincide by displacing each curve parallel to the signal axis. It was possible to determine the mean scale shape for each basis metal for an operating temperature of 150° C and thus scale

the test area was then used to calibrate the thermoelectric gauge. The thickness of nickel (and copper) on these test pieces is given in Table 3, together with the range of coating thicknesses encountered in each set of components.

The coulometric instrument was also used to determine the nickel thickness at several points on the remaining articles, and the thermoelectric gauge subsequently applied at three points close to the test area. To avoid any bias in results four different operators were used for the thermoelectric gauge, and care was taken that each was unaware of the true nickel thickness. Readings were taken at random without observing any definite time interval between readings. The error in every reading taken with the thermoelectric gauge is shown in Table 4.

Table 3. Ranges of nickel and copper thicknesses on specimens

Type of plating	Ni on steel		Ni on Cu on steel*		Ni on Cu on Zn*	
(i) Standard test pieces						
Thickness Ni (mil)	0.98	0.36	1.10	0.82	1.50	0.60
Thickness Cu (mil)	—	—	1.20	1.10	0.40	0.27
(ii) Articles tested						
Thickness range Ni (mil)	1.04 to 0.29		1.69 to 0.68		1.53 to 0.32	
Thickness range Cu (mil)	—	—	1.95 to 0.14		0.72 to 0.08	

* Chromium flash present.

the output meter directly in terms of nickel thickness for the given basis metal.

To calibrate the instrument for nickel on steel within the thickness range 0.3 to 1.5 mil the appropriate standards of thickness about 0.3 and 1.5 mil are prepared. The probe is applied to each standard in turn, and the zero control and amplifier gain adjusted until the correct thickness readings are obtained.

When the specimens include a copper undercoat the method of calibration is extremely important. Fig. 7 shows the range of calibration for nickel on copper on steel as the upper thickness is increased. The copper was deposited from a cyanide solution; 'acid' copper shows the same qualitative behaviour. For thin copper undercoats (less than 1 mil) a nickel on steel calibration applies, for thick copper undercoats (2.0 mil) a nickel on copper calibration can be used. When a range of intermediate copper thicknesses occur the instrument must be calibrated against test pieces having the mean copper thickness of the range. Variations in the copper undercoat within normal limits then introduce an additional error of about ± 0.05 mil in the measured nickel thickness. The effect of a copper undercoat is less when the basis metal is zinc, since copper and zinc have almost identical thermoelectric properties and differ only in thermal conductivity.

Industrial trials

To assess the accuracy of the thermoelectric gauge under industrial conditions, trials were conducted using a commercial version of the instrument described above (Nash and Thompson Ltd.). The output meter was directly scaled in terms of nickel thickness.

Components were taken over a period of several weeks from three well-controlled automatic plating baths, to check whether purification or replenishment of the solution affected the thermoelectric properties of the nickel. For calibration the component was taken at random from each bath, and the mean thickness at two selected areas of diameter $\frac{1}{8}$ in. was measured destructively by a coulometric method which had an accuracy to $\pm 2\%$. The nickel deposit adjacent to

Table 4.

Type of plating	Ni on steel	Ni on Cu on steel	Ni on Cu on Zn
No. of components	83	63	42
No. of readings	853	354	216
Results within—			
± 0.05 mil	73%	60%	71%
± 0.10 mil	94%	88%	96%
± 0.15 mil	99%	96%	98%
± 0.20 mil	100%	98%	100%

Conclusion

These results show that the thermoelectric gauge may be used to measure non-destructively the thickness of nickel deposits upon batches of components from the same plating bath. The following accuracies were obtained.

Nickel on steel	± 0.1 mil
Nickel on copper on steel	± 0.15 mil
Nickel on copper on zinc	± 0.1 mil

It has not yet been possible to conduct similar tests for nickel on brass deposits, but laboratory tests indicate that an accuracy to ± 0.1 mil should be obtained with suitable calibration.

Acknowledgments

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Measurement of magnetic field contours

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Abstract

A simple apparatus is described which can be used to plot the field contours of a laboratory magnet, even when the instability of the field in time is comparable with the variations in space. It consists of two super-regenerative oscillators which produce signals at the nuclear magnetic resonance frequencies of the proton samples in their tank coils. One sample is fixed while the second scans the magnetic field, and the field difference between the two probes is presented in frequency units on an electronic counter. The method can be extended to make the field mapping operation completely automatic.

1. Introduction

THE measurement of the spatial distribution of the field strength of a laboratory magnet is commonly carried out by the nuclear magnetic resonance method and the circuit used is often of the type first described by Pound and Knight (1950). This is a radio-frequency oscillating detector tuned to the nuclear resonance condition so as to display the absorption signal on an oscilloscope trace. The oscillator frequency is then a measure of the magnetic field at the probe. The tuning may be either manual, which is tedious when many measurements are required, or automatic, which introduces some complication of the circuit.

Recently Pound and Freeman (1960) have described another type of magnetic resonance detector which has some useful new features. In a certain mode of operation, a super-regenerative oscillator has its frequency determined by the nuclear precession frequency of the sample placed in the tank coil, with only a very small perturbation by the tuned circuit of the oscillator itself. Over a certain range of magnetic field the oscillator frequency automatically follows field changes so as to maintain the resonance condition. This paper describes an adaptation of this device to the problem of measuring magnetic field contours, with a view to simplifying the technique and the equipment required.

2. The problem of magnet field instability

In most magnet systems, the measurement of very small variations of the field in space is complicated by comparable variations in time, for electromagnets are troubled by current instability and temperature drifts, while permanent magnets are specially susceptible to temperature variations. When precautions are taken to avoid mechanical distortion of the magnet by temperature gradients in the yoke, it would seem reasonable to expect it to be the total magnetic flux which is subject to drift and instability while the pattern of field contours remains to a large extent unchanged. Under such conditions, the problem of the variation in total magnetic flux may be eliminated by the use of two measuring probes. One probe would be fixed in the magnet gap to monitor the

total flux while the second probe tracked over the area to be mapped out. Such a system has a further advantage. It could be arranged that the quantity actually measured is a low audio frequency which represents the magnetic field difference between the two probes instead of the radio-frequency corresponding to the total magnetic field, and it would require only a rather simple electronic counter.

3. The apparatus

When a super-regenerative oscillator is made to operate in the incoherent mode, where the pulses of oscillation are triggered off by circuit noise, it is very sensitive to external radio-frequency signals, tending to 'lock on' to them and become phase coherent. The operation of two such super-regenerative oscillators in the same magnet gap at two slightly different frequencies poses a rather formidable shielding problem. Fortunately this may be avoided by ensuring that the two oscillators never fire simultaneously but are pulsed alternately. This suggestion is due to Mr. Solomon (private communication). Fig. 1 shows how a master multivibrator (V1) controls two out-of-step pulse generators (V2 and V3) which in turn fire the two super-regenerative oscillators (V4 and V5).

Knowledge of magnetic field contours is especially useful when a magnet is to be trimmed for use in a high resolution nuclear magnetic resonance spectrometer. Because it has become customary to operate these at high field strengths, often 14000 gauss, the oscillator circuit shown in Fig. 1 has been designed to operate up to 60 Mc/s, the resonance frequency of hydrogen nuclei in that field. Since the oscillator unit has to be kept well out of the magnetic field, it must be connected to the sample coil by two or three feet of coaxial line. At 60 Mc/s the capacity of the tuned circuit has to be quite low and it is therefore not possible to include the capacity of standard coaxial cable directly. Low capacity cable has undesirable mechanical properties, while correct matching of the cable at both ends complicates the circuit and so the rather simple solution described by Buss and Bogart (1960) has been adopted. The tuning coil is placed in the oscillator unit and the centre tap of this coil takes a signal through about two feet of standard coaxial line to a second coil containing the proton sample.

The operation of the super-regenerative oscillator has been described in detail by Pound and Freeman (1960). Essentially the oscillator has to be brought to one of the two tuning positions which allow the establishment of a steady state where each oscillation pulse is triggered by the fixed nuclear precession signal in the sample coil. To this end the radio-frequency pulse envelope is displayed on an oscilloscope. When the oscillator is incoherent this appears as a superposition of many pulses of different amplitude (Fig. 2(a)), but when it is correctly tuned the envelope greatly increases

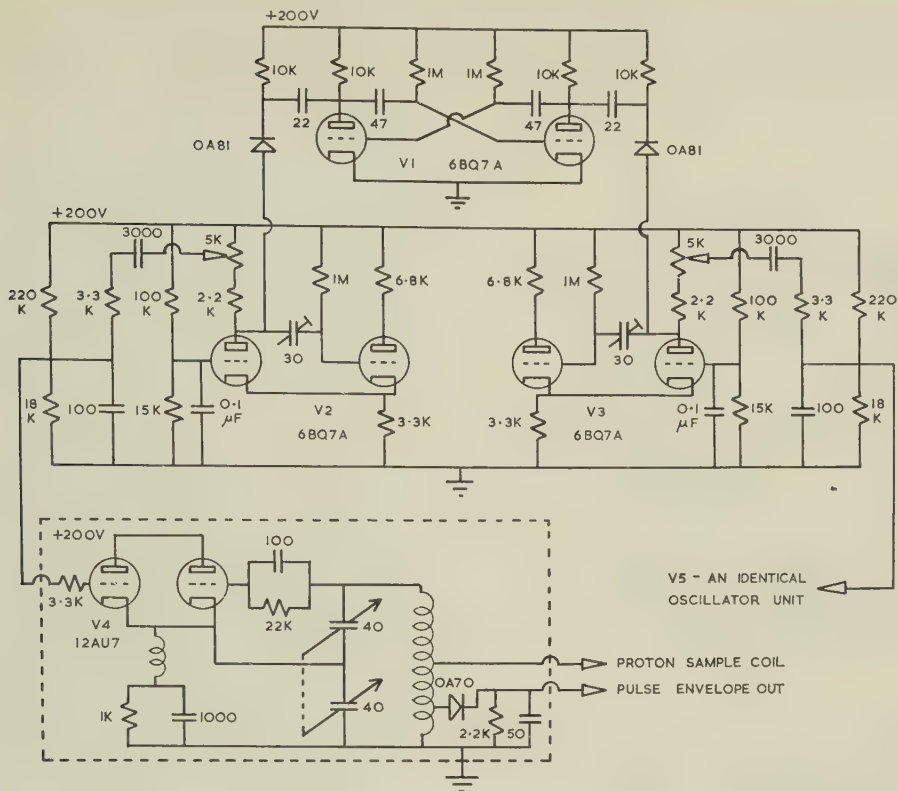


Fig. 1. The super-regenerative oscillators and associated timing circuits.

amplitude and loses its noisy character (Fig. 2(b)). It is tuned to maximum pulse height and then its field tracking accuracy is optimum.

The fractional error R , which the device makes in following change in magnetic field has been shown theoretically (Gould and Freeman 1960) to be approximately τ/T_1 where τ is the width of the radio-frequency pulse and T_1 is the in-lattice relaxation time of the protons in the sample. The time constant in the cathode of the oscillator determines τ which is about $1 \mu\text{s}$ in present experiment. The water

plane of the magnet gap, so the fixed probe should be set nearer to one of the pole faces.

Now the frequency difference between the two oscillators is not necessarily the exact equivalent of the magnetic field difference between the two probes, for it depends somewhat on how well each oscillator has been tuned, but the changes in this frequency difference do correspond almost exactly to the changes in the field difference. The beat frequency between the two oscillators may be conveniently picked up on a communications receiver tuned near 60 Mc/s and set to receive amplitude modulation. The audio-frequency output from this receiver is then filtered to remove components at the quench frequency (about 27 kc/s), and fed to an electronic counter. This is the only way in which the pulse nature of the super-regenerative oscillator signal intervenes, for the receiver does the necessary filtration of unwanted sidebands.

4. Limitations of the super-regenerative oscillator method

sample contains dissolved ferric alum and normally has $\tau = 1$ ms. The tracking error R is thus of order of magnitude 1 in 10^3 and this also represents the amount of 'frequency pulling' when the oscillator circuit becomes slightly detuned. In order to reduce such detuning to a minimum, the moving probe has its coaxial line held rigidly inside a copper tube, the oscillator unit and sample moving as a whole as the field is mapped out. In this way it is quite unnecessary to retune the oscillator after every move. It is desirable to leave a completely free path for the scanning probe in the central

Provided that magnetic field instabilities are limited to less than about ten times the range of magnetic field covered by the contours, then the error which the oscillator makes in recording the field may be neglected, since R is such a small fraction. It is the perturbation by the oscillator tuned circuit which appears to impose a practical limit on the precision with which the contours may be measured. The natural frequency instability of the tuned circuit induces instabilities in the super-regenerative oscillator frequency, reduced by a factor $1/R$. The extent of this effect may be judged by a simple experiment. The two probes were clamped side by side in the magnet gap and the frequency difference

between the two super-regenerative oscillators monitored by means of a frequency counter measuring to ± 0.1 c/s. Samples with a relaxation time $T_1 = 7$ ms were used. The result is shown in Fig. 3, A, from which it can be seen that

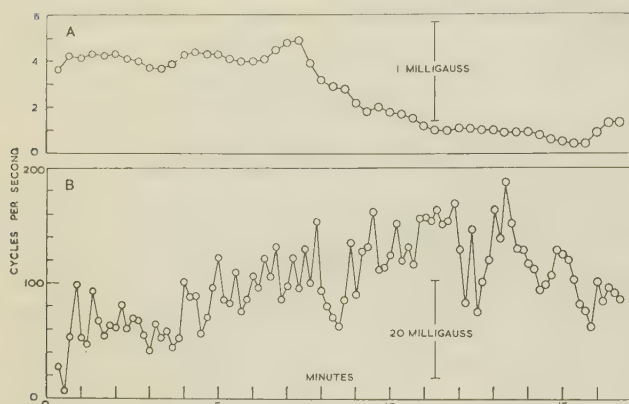


Fig. 3. A. The instability of the audio-frequency beat between two super-regenerative oscillators placed side by side in the magnetic field. B. The instability of the magnetic field measured over a similar period of time. Note the change of vertical scale.

the precision that can be expected is of the order ± 1 mg. This should be compared with Fig. 3, B, which is an actual plot of magnetic field variations made by beating the frequency of a single super-regenerative oscillator against a crystal controlled source. It is of interest to note that no improvement was observed when the first of these experiments was repeated with a magnetic field 'superstabilizer' (Varian Associates, California) in operation although this device is known to improve field stability by about two orders of magnitude. It must be concluded that the use of two probes has so nearly eliminated the field instability effect that it is smaller than the residual frequency instability. Consequently the field mapping experiments were carried out without the use of the superstabilizer.

Previous experiments (Pound and Freeman 1960) have established that the super-regenerative oscillator will operate effectively over a range of magnetic field of the order of 10 gauss. In the present application, the magnetic field

inhomogeneity over the sample volume imposes a more severe practical limitation. The oscillator operated correctly only when the probe was in a region where the time constant of the decay of the free precession signal was determined by the dissolved paramagnetic ions T_1 rather than by magnetic field inhomogeneity T_2^* . Outside this region low-frequency relaxation oscillations described by Pound and Freeman (1960) became troublesome, usually causing the oscillator to lose coherence. Choice of the concentration of paramagnetic ions is therefore a compromise. A long spin-lattice relaxation time improves the regulation factor while a short one increases the field inhomogeneity which the device will tolerate. This inhomogeneity effect could be further reduced by the use of a smaller sample; in the present experiment the effective sample volume was 0.05 ml.

5. Experimental test

A high resolution nuclear magnetic resonance spectrometer may be used to map out a magnetic field provided that it is fairly homogeneous and extremely stable. The field of a Varian 12 in. electromagnet was mapped out in this way with the Varian 60 Mc/s high resolution equipment. The superstabilizer was adjusted so that magnetic field drift could be neglected over the period required for the measurements. The field sweep was calibrated by imposing modulation sideband signals at a known audio frequency, and the position of the resonance line on the oscilloscope trace was measured as the probe was moved from point to point in the magnet gap. The probe carriage could be wound by means of screw threads up-and-down and back-and-forth, so that the results present themselves on a square grid at the intersections of which the field strength is recorded. By interpolation the position of the field contours may be found and the result is shown in Fig. 4, A.

This was the control experiment used to check the operation of the super-regenerative oscillator method. The field contour map obtained in this way is shown in Fig. 4, B, and it is clear that all the essential features are the same.

6. An automatic field mapping apparatus

Even with a magnetic field meter which does not need retuning when moved from one point in a magnetic field to another, the field mapping operation can be extremely tedious; moreover the interpolations required to convert

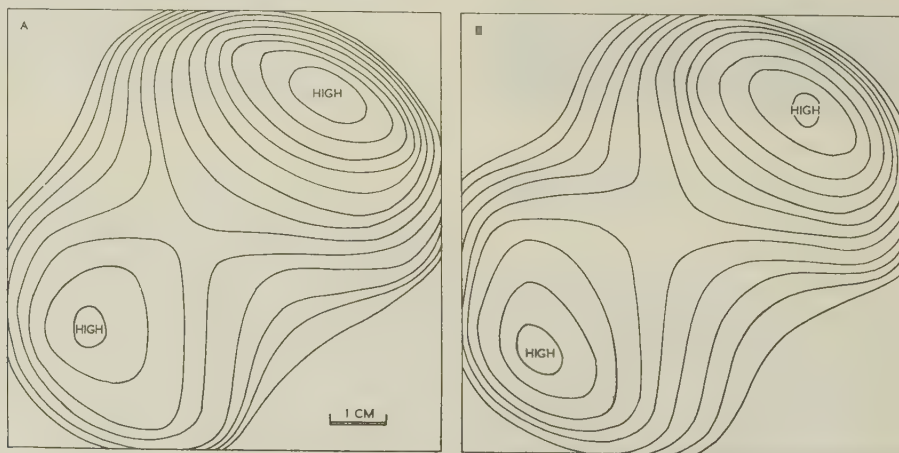


Fig. 4. A. Magnetic field contours measured at intervals of 10 mg by means of a high resolution nuclear resonance spectrometer and a field 'superstabilizer'. B. The same area mapped out later by the super-regenerative oscillator method, but with no field 'superstabilizer'.

measured values to a contour map are equally laborious. When the ultimate aim of such measurements is the adjustment of the magnet to give a more homogeneous field, and a fresh map may then be needed after each adjustment. The obvious answer is to make the whole operation automatic. The magnetic field meter described above has two properties which make it specially suitable for automatic operation. It records spatial variations of magnetic field without the need for retuning, and it presents this information in quite convenient form, as an audio frequency.

The first step is to make the scanning system automatic by coupling suitably geared electric motors to the positioning controls of the probe carriage. Then, as the proton sample is driven through a point where the magnetic field strength corresponds to one of the predetermined values which define a field contour, its position is plotted on a chart. Eventually a complete contour map will be built up in this way.

For the magnetic resonance of hydrogen nuclei, 1 mg is equivalent to 4.26 c/s. Magnetic field contours may therefore be represented by a set of audio frequencies separated from one another by a suitable multiple of 4.26 c/s. The problem is then to plot the position of the sample probe whenever the audio-frequency output of the communications receiver becomes equal to one of these set frequencies. There are several ways in which this may be done. It is possible to modify a frequency counter in such a way that whenever certain frequencies are displayed a relay is operated. Another method would be to use a set of sharply tuned resonant circuits to pick out the required frequencies. A very similar problem is solved in radio-controlled model aircraft by a set of tuned vibrating reeds which make electrical contact when set into oscillation by an audio-frequency signal at the resonant frequency. Finally, the simplest and most flexible method would seem to be the lock-in detector, the operation of which is described below.

The audio-frequency signal from the receiver is fed into a mechanical chopper driven at a frequency equal to half the interval between contours. This generates an output across the balanced detector only when the signal is at the chopper frequency or an odd harmonic. This response is made to operate a relay driving a marker pen attached to the super-regenerative oscillator unit used to scan the magnetic field. In this way the pen performs exactly the same scanning movements as the nuclear resonance probe (but outside the magnetic field) and there are no problems arising from backlash in the carriage driving mechanism. One particular merit of this lock-in detector method is that the contour interval may be set at will, simply by adjusting the chopper drive frequency. 50 mg contours are obtained with the chopper operating at 106.5 c/s.

A typical chart is shown in Fig. 5, and it can be seen that the general shape of the magnetic field contours is well

reproduced. Close examination reveals the presence of a few 'ghost' contours which appear to be occasional responses to the even harmonics of the chopper frequency, probably

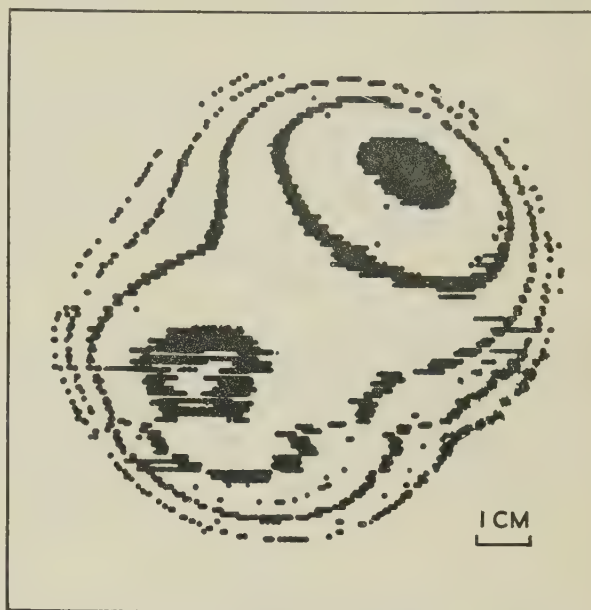


Fig. 5. Actual field contour chart obtained automatically. The plot was made several weeks later over the region covered by Fig. 4. Contour intervals 50 mg.

caused by circuit unbalance. Apart from this rather trivial problem, the result indicates that the scheme could be developed to make a quick, reliable and completely automatic field mapping device.

Acknowledgments

The work described above has been carried out as part of the research programme of the National Physical Laboratory, and this paper is published by permission of the Director of the Laboratory.

The author would like to acknowledge the helpful discussions he has had with Mr. I. Solomon, Mr. D. G. Moss and Mr. V. Johnson.

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Automatic method of magnetic field calibration using proton resonance

by A. HORSFIELD, J. R. MORTON and D. G. MOSS, Basic Physics Division, National Physical Laboratory, Teddington, Middlesex

MS. received 8th March 1961, in revised form 12th April 1961

Abstract

A circuit is described which enables the automatic calibration of a magnetic field to be carried out. A marginal oscillator, frequency controlled by one of eleven quartz crystals mounted in a motorized turret tuner, detects nuclear magnetic resonance signals. These signals activate a pen recorder and also trigger a control circuit which advances the turret tuner to the next channel.

in measuring hyperfine electron spin resonance splittings than had previously been possible by manual methods.

2. Transistorized marginal oscillator

The transistorized proton resonance detector (Fig. 1) has the advantage of compactness and ease of construction, but its signal-to-noise ratio was less than that of the vacuum-tube type to be described in § 3.

Transistor T_1 functions as an r.f. oscillator, frequency controlled in the range 13–14 Mc/s by one of eleven quartz crystals selected in turn by the turret tuner. The frequency interval between successive crystals was 75.9 ± 0.1 kc/s. The centre crystal having a frequency of 13.6640 ± 0.0001 Mc. This frequency corresponds to a magnetic field of 3209.4 G at which field the e.s.r. of diphenyl picryl hydrazyl occurs at 9000 Mc/s. Field markers were obtained from this set of crystals at equal intervals of 17.83 G, corresponding to a change of 50.00 Mc/s in the microwave frequency. It was

1. Introduction

THE device to be described was developed to calibrate the slowly varying magnetic field during electron spin resonance experiments. By controlling the frequency of a conventional proton resonance probe (Pound and Knight 1950), with a number of quartz crystals of suitable frequencies (Blume 1958, Garwin, Patlach and Reich 1959), field markers were obtained every 18 gauss. The side pen on a pen recorder

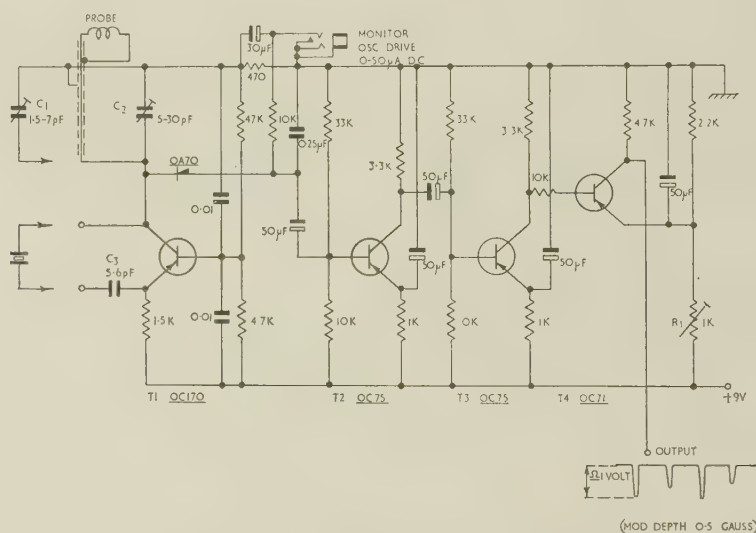


Fig. 1. The transistorized marginal oscillator.

and a motorized turret tuner (available commercially for television and supplied by Brayhead Products Ltd.) were activated by the phase detected nuclear magnetic resonance signals and a gating circuit described in § 4. The turret tuner was used to switch automatically from one crystal to the next. This resulted in greater accuracy and convenience

found that the oscillator could be locked to the crystal frequency without pulling and that the signal-to-noise ratio of the free-running oscillator was maintained. The r.f. level at the probe coil (27 turns $\frac{1}{4}$ in. diameter, 0.036 in. copper wire) is detected by a germanium diode, and amplified by transistors T_2 and T_3 . Transistor T_4 provides additional

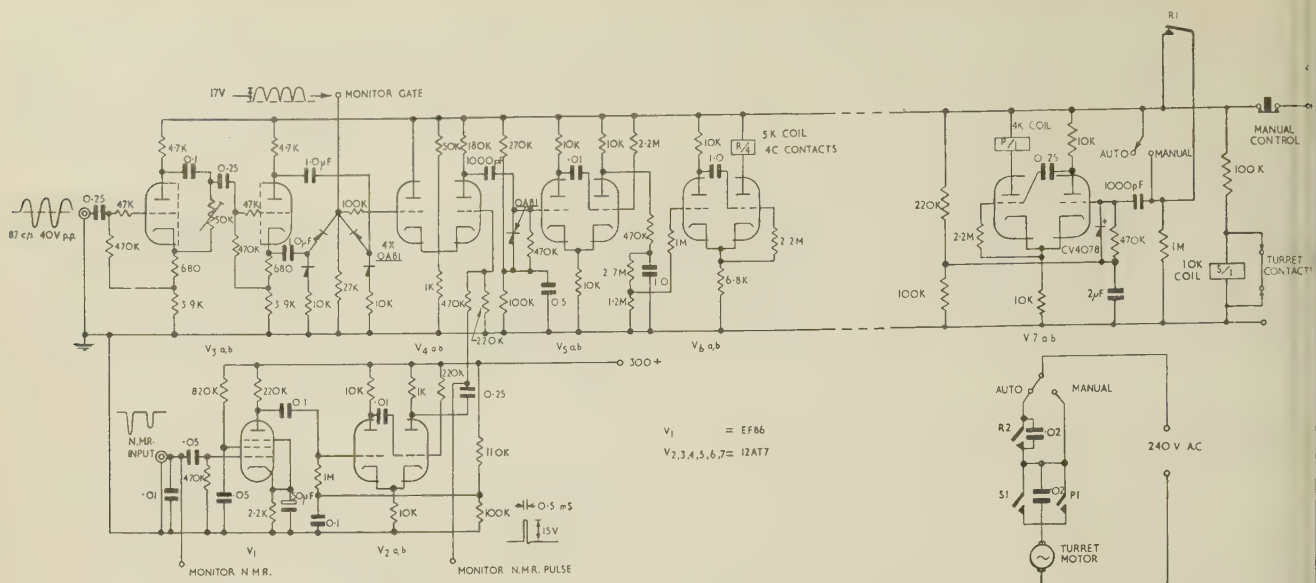


Fig. 4. The automatic gating and motor control circuit.

and S1) and when the next channel position is reached S1 is opened and the motor stops. The additional relay S/1 is used to avoid using 240 v a.c. inside the turret tuner. A manual/auto switch allows the selection of the starting point in the sequence of crystals with the manual control button.

By measuring the position of the diphenyl picryl hydrazyl line with a spectrometer operating at 9000 Mc/s the device was shown to be accurate to one part in 5×10^4 . Since the signal-to-noise ratio of either n.m.r. detector was sufficient to prevent the gating circuit being fired by noise, the factor limiting the accuracy of the device is the finite gate width. With a narrower gating waveform the accuracy of the device could be made to approach that of the quartz crystals.

Acknowledgments

This work forms part of the research programme of the Basic Physics Division of the National Physical Laboratory and is published by permission of the Director. We would like to thank D. H. Whiffen, R. Freeman and W. Wilson for helpful discussions.

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Ultra-violet absorption optical system with photoelectric recording for a Phywé ultracentrifuge

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S. received 1st March 1961

Abstract

An ultra-violet absorption optical system has been constructed for an air-driven Phywé ultracentrifuge. The intensity of a parallel beam of ultra-violet light transmitted through the solution in an ultracentrifuge cell is measured by forming the enlarged cell image with a photomultiplier. The electronic circuit permits the measurement of both transmission and optical density.

1. Introduction

THE sedimentation velocity and the sedimentation coefficient distribution of deoxyribonucleic acid (DNA) in solutions of low concentration (in the range from 0.1 to 300 $\mu\text{g/ml}$) can be measured by means of an ultra-violet absorption optical system (Shooter and Butler 1956, Humaker and Schachman 1957) using light with a wavelength of about 260 $m\mu$.

To the authors' knowledge, only photographic recording methods have been used successfully in such a system (Wedberg and Pedersen 1940), e.g. on the model E ultracentrifuge by Beckman (Spinco Division). Several difficulties arise, however, inherent to this method.

The photographic material must be highly sensitive to wavelengths of about 260 $m\mu$ to avoid long exposure times. On the other hand, it should be insensitive to other wavelengths that may be transmitted by the filters used in the system, e.g. wavelengths longer than 500 $m\mu$ for chlorine and bromine filters. Exposure times must be adjusted in such a way that the densities of the exposed part of the photographic material fall within the linear range of the curve. The detectable differences of DNA concentrations are limited by the extent of this linear region. The developing procedure must be standardized.

For very accurate measurements it is advisable to record the transmission of the buffer solution and some well-known DNA concentrations, together with that of the experimental DNA solution, on the same sheet of film. As the movement of the sedimenting boundary cannot be observed during a run, a preliminary experiment is sometimes necessary to determine the optimal rotor speed, exposure time and interval between exposures.

These difficulties can be circumvented by using a photoelectric recording system.

2. The optical system

The optical components are shown schematically in Fig. 1. The light source A is a Philips HP 125 mercury lamp, type 103.107. In a discharge tube of this type, two diaphragms with circular holes are mounted close to the electrodes.

These diaphragms stabilize the arc by preventing wall-to-wall jumping of the discharge. The tube is fed with electronically stabilized direct current. Despite these precautions some instability in the light intensity remains.

A metal diaphragm B, with a diameter of 2 mm, has been

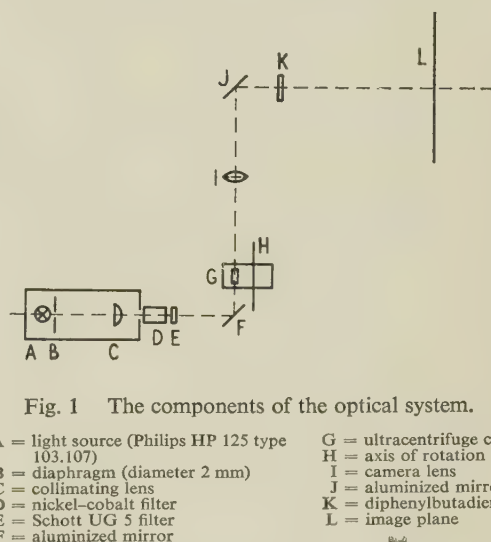


Fig. 1 The components of the optical system.

- | | |
|--|------------------------------|
| A = light source (Philips HP 125 type 103.107) | G = ultracentrifuge cell |
| B = diaphragm (diameter 2 mm) | H = axis of rotation |
| C = collimating lens | I = camera lens |
| D = nickel-cobalt filter | J = aluminized mirror |
| E = Schott UG 5 filter | K = diphenylbutadiene filter |
| F = aluminized mirror | L = image plane |

placed close to the discharge tube. As a result only a small fraction of the light emitted by the lamp is used. However, a point source is thus more closely approximated. The quartz collimating lens C is a plane convex lens with a focal length of 30 cm and a diameter of 60 mm.

Filters are used to isolate a narrow band of wavelengths at about 260 $m\mu$. These are the types described by Kasha (1948) with some minor modifications: (a) 5 cm of a solution containing 240 g $\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$ and 45 g $\text{CoSO}_4 \cdot 7\text{H}_2\text{O}$ per litre of water; (b) 1 cm 1:4 diphenylbutadiene solution, concentration 42.4 mg/l., dissolved in distilled alcohol (instead of ether); (c) 1 mm UG 5 filter, made by Schott-Jena. This filter has a somewhat higher transmission at 260 $m\mu$ than the Corning filter No. 9863 recommended by Kasha. These filters isolate the mercury lines with wavelengths of about 254 and 265 $m\mu$. The nickel-cobalt filter D and the Schott UG 5 filter E have been placed between the collimating lens C and the ultracentrifuge cell G on the lower optical bench. Since its absorption characteristics are changed by ultra-violet light, the diphenylbutadiene filter K has been placed on the upper bench where it receives less irradiation. Even so, it must be replaced every day. The stock solution is stored in the refrigerator.

The quartz camera lens I is a biconvex one with the same focal length and diameter as the collimating lens. It produces an approximately three times enlarged vertical image of the cell centrepiece at L.

This image is scanned by means of an RCA photomultiplier type 1 P 28 placed behind a small horizontal slit, 0.3 mm wide and about 7 mm long. This slit is placed in the image plane L of the camera lens. To avoid fatigue of the photocathode a small cylindrical quartz lens has been mounted between the slit and the photomultiplier. The detector system can move up and down behind a vertical rectangular slit, length about 50 mm, width 5 mm, the width being somewhat smaller than the width of the cell image. The movement is accomplished by means of a synchronous motor (Berger RSM 48).

The precise adjustment of the optical system is of utmost importance. The absorption of light must be measured in a relatively small part of the sedimentation path, especially when the boundary has moved only a small distance from the meniscus. Therefore, the light beam through the cell should be essentially parallel.

The optical system is adjusted by the following procedure. First the optical benches and both aluminized mirrors F and J are adjusted. Diaphragms with holes, 2 mm in diameter, are placed at fixed points, viz. at the central point of the vertical slit before the photomultiplier, in the centre of the lens holders and on the quartz plates in the bottom and top of the vacuum chamber. A strong light source is substituted for the photomultiplier and the mirrors F and J are adjusted in such a way that the small beam of (visible) light passes through all diaphragms, including the diaphragm B.

After this adjustment has been made, the strong light source and the diaphragms are removed (except B) and the collimating lens C and the filters D and E are put in place, because the collimating lens has to be adjusted with ultra-violet light.

A fluorescing screen is then placed at some distance on the right-hand side of L, the vertical rectangular slit being temporarily removed, and the collimating lens is moved to and fro on the optical bench until the diameter of the fluorescing spot equals that of a diaphragm placed close to the filters.

The camera lens I is focused by making photographs of a thin wire, placed below the upper quartz window inside the ultracentrifuge cell, at different positions of the camera lens.

After the focusing adjustments have been made, the vertical slit is mounted and the photographic plate is replaced by a sliding plate carrying the photomultiplier. Care has to be taken that the horizontal slit moves in the image plane of the camera lens.

3. The electronic system

The photomultiplier receiving the pulses of transmitted light is operated at a potential of 800 volts. The frequency of the light pulses is determined by the rotor speed and varies between 200 and 800 pulses per second, corresponding to 12.000 and 48.000 rev/min. The length of the light pulses is dependent both on rotor speed and on the angle of the cell centrepiece. It ranges from 10 to 60 μ s for the Phywé cells.

Because the cell centrepiece has a sectorial form and the light pulses are measured behind a rectangular slit, the light pulses transmitted near the meniscus are of the same length as those transmitted near the cell bottom.

The average photomultiplier current due to the light pulses is a measure of the light intensity transmitted through the cell. The average current is as low as 2.5×10^{-8} A for a

buffer solution because of the smallness of the light source, the absorption of light in various parts of the optical system and the short pulse duration as compared with the time interval between pulses. Therefore, the dark current of the order of 10^{-9} A is not negligible. However, as the dark current is constant at constant temperature it can be easily balanced.

The fluctuations in the anode current due to the pulse character of the photocurrent, statistical variations of photo-

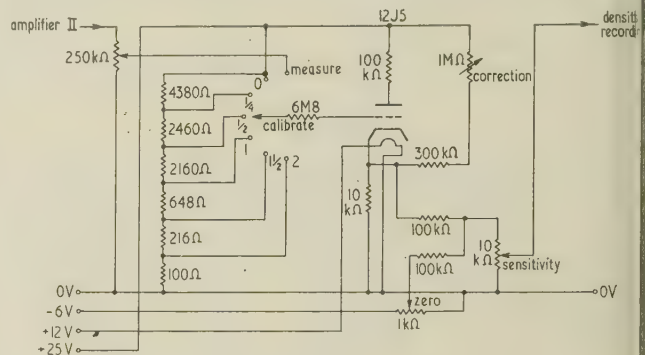


Fig. 2. Diagram of the logarithmic converter.

current and dark current, and irregularities in the light source are moderated by means of a capacitor in parallel with the anode resistor. The time constant of this network is about 0.2 second. It should not be made much larger because a strong gradient in light intensity along the cell image should be recorded properly using the scanning time chosen, viz. 2 minutes.

The voltage across the photomultiplier anode resistance is amplified by means of a d.c. amplifier. The dark current is eliminated by adjusting the output of this amplifier at zero when the photomultiplier receives no light. The output voltage from this amplifier is corrected for non-uniform light intensity along the cell image using a 'base line correction unit', which consists of a variable attenuator coupled mechanically with the scanning system. With some cells the light intensity is so uniform that the correction unit is not required. Non-uniform intensity is usually a result of non-sectorial centrepiece.

When a DNA solution is centrifuged, the output voltage from the 'base line correction unit' varies in proportion with the transmission of ultra-violet light through the cell and can be used for recording. The transmission is converted

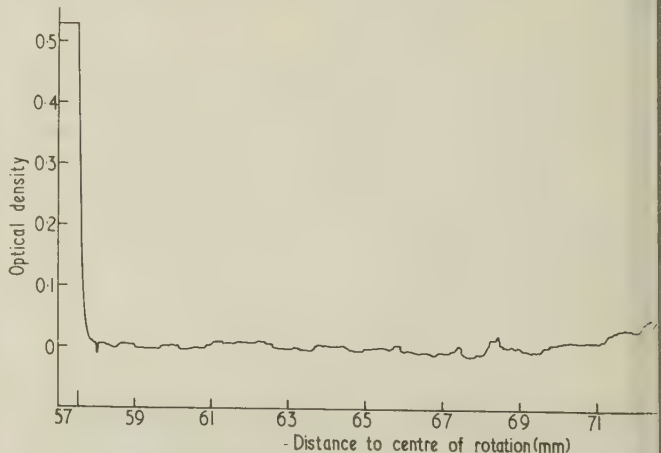


Fig. 3. Base line record.

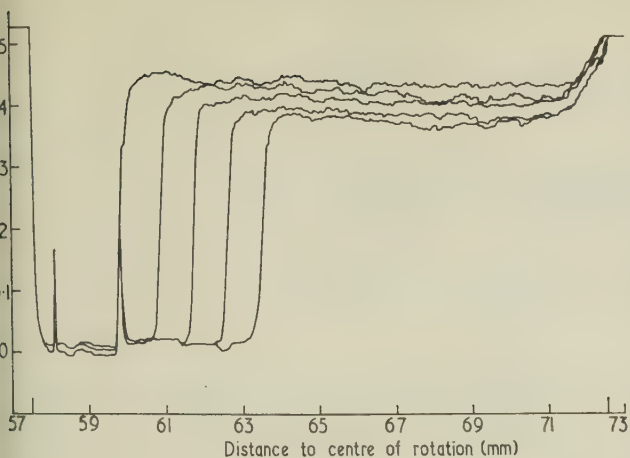


Fig. 4. Curves obtained during centrifugation of a DNA solution.

Sample: DNA isolated from bacteriophage T4, concentration $20 \mu\text{g/ml}$. Buffer: $0.14 \text{ M NaCl} + 0.02 \text{ M sodium citrate}$, pH 7. Rotor speed: 15000 rev/min . Cell: 12 mm light path . Temperature: 14.5°C .

Records were made 0, 35, 65, 95 and 125 minutes after reaching the desired rotor speed.

electronically to optical density by means of the following (preliminary) device. The voltage from the correction network is amplified by a second d.c. amplifier and then used to feed a logarithmic converter based on the approximately logarithmic relation between anode and grid current of a

triode over a certain range. The circuit is shown in Fig. 2. With the 'zero' and 'correction' potentiometers the triode is adjusted properly using fixed calibration potentials corresponding to optical densities of 0, 0.25, 0.5, 1, 1.5 and 2. By means of the potentiometer controlling the sensitivity the full-scale deflection of the recorder can be set equal to any optical density between 0.5 and 2. The optical density of a buffer solution is set zero by means of the potentiometer at the input of the converter.

A base line record is demonstrated in Fig. 3. Fig. 4 shows an example of the curves obtained when a DNA solution is centrifuged.

The authors hope to make further improvements in the future by employing a silicon diode for the logarithmic conversion and by increasing the stability of the system. They also intend to provide an electronic correction for the radial dilution effect.

Acknowledgments

Our thanks are due to Mr. W. de Vries for his technical assistance during the early stages of the experiments.

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Apertometer for microscope objectives

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MS. received 29th March 1961

Abstract

In conventional apertometers accuracy is limited by parallax between the effective aperture stop and the scale image. This is overcome by the use of a projection system in the device described.

IN the course of a programme of work in which the performance of microscope objectives in imaging isolated objects is being critically studied, it has been necessary to measure numerical aperture rather more precisely than is usual. The well-known Abbe and Beck apertometers have been found to be inconvenient for this purpose because it frequently happens that the images of the scales in these devices are not formed in the same plane as the effective limiting aperture of the objective; this produces parallax and the resulting uncertainty about the correct numerical aperture may exceed several units in the second decimal place for an oil-immersion objective.

In the authors' instrument a pinhole in the primary image plane of the objective is illuminated by means of a high-pressure mercury lamp; an image of this pinhole is formed at the object plane of the objective and the light then spreads out into a cone of angle corresponding to the N.A. of the objective; a hemispherical lens with its convex surface lightly ground is placed with its plane polished face at the focus, and the angle of the cone is measured by the diameter of the bright patch on the ground surface. The detailed arrangement is shown in the Figure. The 250 w mercury lamp, G.E.C. type ME/D, has a luminance of about 20 000 sb; the pinhole is 1 mm in diameter and is mounted in place of the eyepiece in a microscope body with variable tube-length. The hemispherical lens is made with central thickness 0.2 mm greater than the radius (33 mm) of the spherical surface, so that oil immersion lenses can be oiled into contact with the plane surface. The scale is graduated in divisions of 0.02 of N.A.

A thick parallel-sided block of glass, with its second surface ground, could have been used instead of the hemispherical lens, in which case the apparatus would be almost

equivalent to a Beck apertometer used back-to-front; however, it is easy to show that the illumination on the ground surface would fall off as the fourth power of the cosine of the

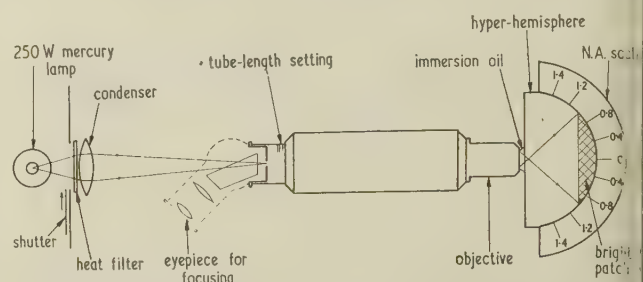


Diagram of apertometer for microscope objectives.

convergence angle in the glass, assuming the objective to be aplanatic, thus giving a sixteen-fold change in illumination from centre to edge of the bright patch on the ground surface for an oil-immersion objective. With the hemispherical lens the change in illumination is only linear with the cosine of the convergence angle.

The method of use is as follows for 'dry' objectives. The light from the mercury lamp is shuttered off, the pinhole is replaced by an inclined eyepiece, shown dotted in the Figure, and the objective is focused on small scratches on the plane surface of the hemisphere. The eyepiece is removed, the pinhole replaced and the N.A. can then be read directly on the scale. (To be perfectly accurate the objective should be focused on a point 0.2 mm below the plane surface of the hemisphere, but in fact the error in N.A. cannot exceed about 0.003, even with a dry objective of 0.9 N.A., and is generally much less.) Oil immersion objectives are simply oiled straight on to the surface.

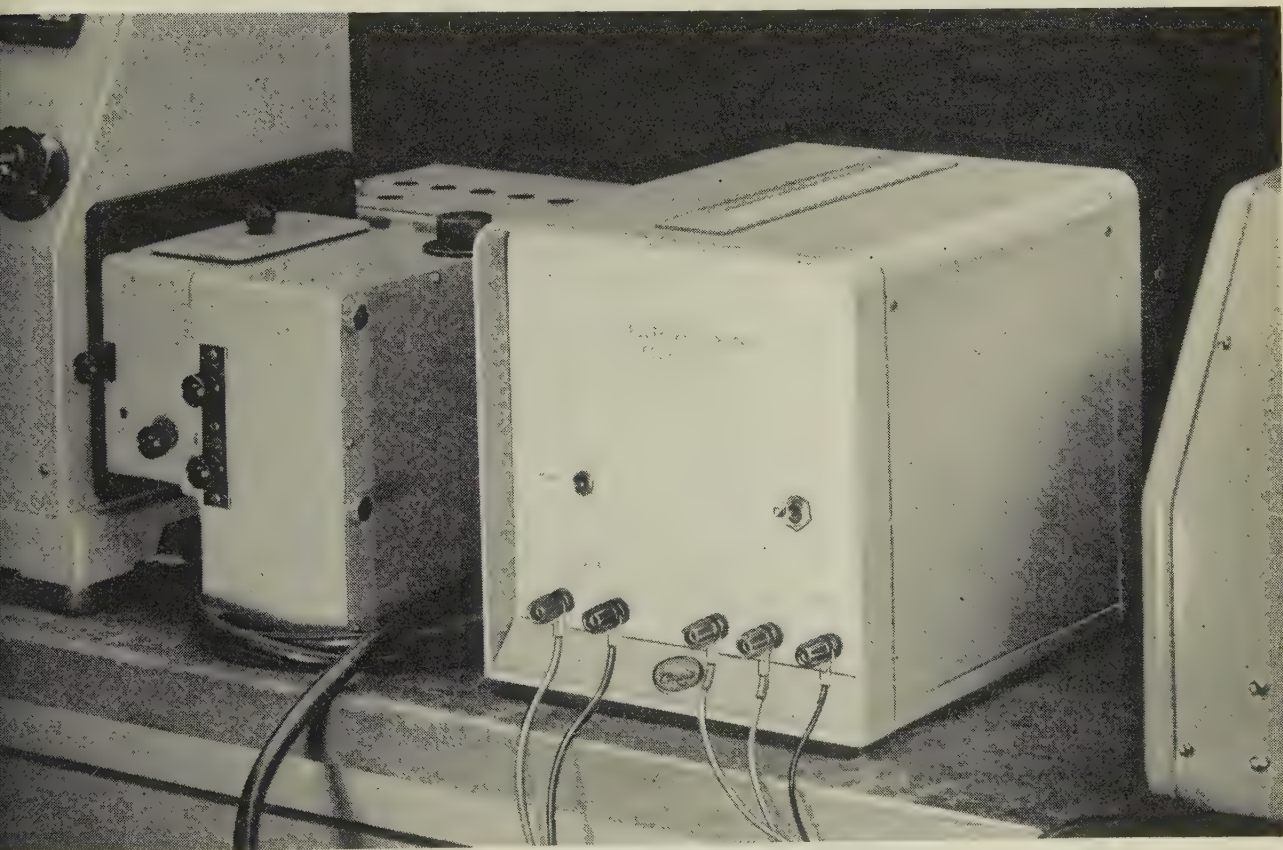
Acknowledgment

Acknowledgment is made to the National Coal Board for a grant in aid of this research. The opinions expressed are those of the authors and not necessarily those of the Board.



SPECTROPHOTOMETER POWER SUPPLY-115D

Designed to replace the use of an accumulator with the Unicam SP500 Spectrophotometer, the Labgear Power Supply is guaranteed not to impair the operation of the Spectrophotometer. Particular care has been taken to minimise the temperature rise of the sample and control components due to the heat dissipation in the series regulators. The use of the latest type power transistors together with cast alloy heat sinks permit the unit to operate at high ambient temperatures under adverse mains input conditions. First quality components are employed throughout, making the unit suitable for pan-climatic use.



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SPECIFICATION

CATHODE-RAY TUBE: 5 in. (12.7 cm) diameter screen, single-beam, operating at 10 kV. Green fluorescence—phosphor P1. Phosphors P7 and P11 available to special order. Display area 10 cm (horizontal) by 6 cm (vertical).

Y AMPLIFIER: Basic Model 1076; d.c. to 80 Mc/s (30% down); rise-time 5 μ sec; sensitivity 200 mV/cm. With plug-in unit Model 1078; rise-time 6 μ sec to 7 μ sec; 50 mV/cm to 50 V/cm calibrated. With plug-in unit Model 1080; d.c. to 1 Mc/s (30% down); 1 mV/cm to 50 V/cm calibrated (differential inputs). With plug-in unit Model 1081; 3 c/s to 40 Mc/s (30% down); rise-time 10 μ sec; 5mV/cm to 2 V/cm calibrated or, d.c. to 60 Mc/s, 50 mV/cm to 20 V/cm. With plug-in unit Model 1085; d.c. to 40 Mc/s (30% down), dual-channel beam switch; rise-time 10 μ sec; 50 mV/cm to 20 V/cm calibrated.

SIGNAL DELAY: 150 μ sec.

TIME-BASE: 24 calibrated ranges from 0.1 μ sec/cm to 5 sec/cm in a 1, 2, 5 series. Continuously variable un-calibrated ranges from 0.1 μ sec/cm to 12 sec/cm. Calibrated sweep expansion of $\times 1$ or $\times 5$ on all ranges from 0.1 μ sec/cm to 12 sec/cm. D.C. coupled bright-up pulse to CRT grid gives uniform brightness along the trace length and complete fly-back suppression on all ranges. Scan length: 10 cm.

TRIGGER: with plug-in unit Model 1079—five modes of operation, H.F. Sync, Auto, A.C. Fast, A.C. Slow, and D.C. With plug-in unit model 1083—as given above for model 1079 and also with calibrated delayed sweep ranges: 100 μ sec, 1 msec, 10 msec, 50 msec. With plug-in unit Model 1082—calibrated sweep delay from 2 μ sec to 10 sec. Separate trigger selection for main sweep and

delaying sweep. Trace may be displayed on delaying sweep. "Lock-out" delay for jitter-free operation.

X AMPLIFIER: with plug-in unit Model 1079—d.c. to 2 Mc/s. 1V/cm to 100 V/cm calibrated. With plug-in unit Model 1083 as given above for Model 1079.

CALIBRATION: Amplitude. A 1 kc/s square-wave calibration source provides eighteen fixed voltage levels from 0.2 mV to 100 V peak-to-peak in a 1, 2, 5 series. Accuracy is within 2 per cent.

Time. Basic calibration ranges are within ± 3 per cent. In addition, a gated 500 ($\pm 2\%$) Mc/s oscillator can be switched in to provide 2 μ sec intensity modulation dots for accurate measurement of pulse rise-times. Time marker pips are also available at 50 ($\pm 2\%$) Mc/s.

OUTPUT WAVEFORMS: time-base saw-tooth and gate; vertical-amplifier output; 1 kc/s calibrator square wave.

GENERAL: small neon indicators show the direction in which the CRT beam lies when deflected off the screen. An illuminated rotatable graticule with anti-parallax ruling in centimetre squares with 2 mm base, line divisions and green filter is provided. Fittings for camera attachment.

POWER SUPPLY: Mains. 100 V to 130 V and 200 V to 250 V. Frequency. 50 c/s to 100 c/s. Consumption. 650 W (approximate). Stabilized E.H.T., H.T. and transistor-stabilized d.c. heater supply to drift and hum-sensitive circuits.

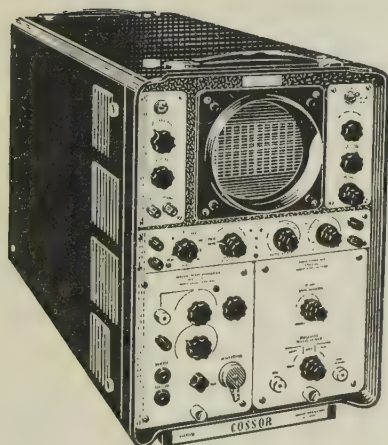
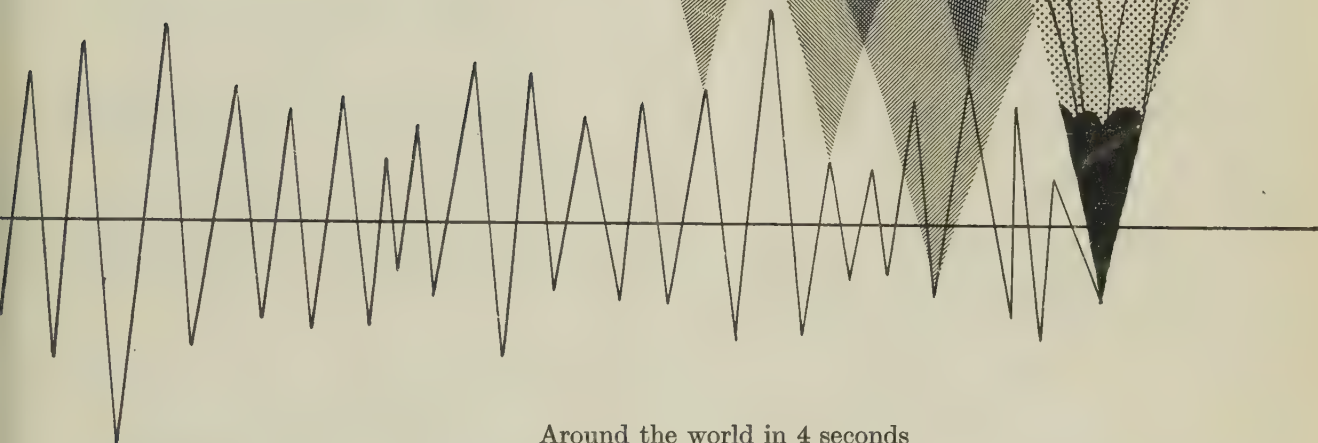
SIZE AND WEIGHT: Height 18 $\frac{1}{2}$ in. (47.0 cm). Width 13 in. (33.0 cm). Depth 29 $\frac{1}{4}$ in. (74.3 cm). Weight with two plug-in units 104 lb (47.3 kg).

ACCESSORIES: Probe Model 1077. Camera Model 1458.

Full details of plug-in units will be supplied on application.



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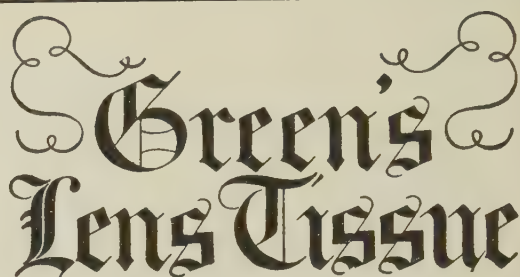
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Suppressed zero d.c. voltmeter

R. E. AITCHISON, M.Sc., School of Electrical Engineering, University of Sydney

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This note describes a simple suppressed zero d.c. voltmeter which may be constructed using Zener diodes and a standard multimeter or other moving coil meter. A typical application is in the testing of regulated power supplies.

The basic principle is to supply one terminal of a meter with a fixed voltage, derived from the voltage being measured, using the cascaded Zener diodes Z_1 and Z_2 . The other terminal of the meter is supplied with an identical d.c. voltage, derived from the complementary arrangement of cascaded Zener diodes Z_3 and Z_4 . However, for this complementary arrangement of diodes almost all of the variations in the input voltage are transferred to the meter M. If we define the efficiency E of the suppressed zero system by

$$E = \frac{\text{actual change in voltage at meter terminal}}{\text{change in input supply voltage}}$$

for perfect Zener diodes with zero slope resistance E is 100%. By using two Zener diodes in cascade the value of E closely approaches 100%, so that in the design of the meter few of the variables are critical. The main design considerations are the selection of the particular Zener diode operating voltages and currents to give correct performance.

As the lower limit of V_{input} is in the vicinity of 12 v, 3 to 4 v being the lower limit of the rating of typical Zener diodes. Using single diodes for Z_2 , Z_3 and Z_4 the upper limit would be in the vicinity of 50 v, but as the number of diodes in series could be used for each of the diodes Z_2 , Z_3 and Z_4 this upper limit could be extended arbitrarily.

As the slope resistance of Zener diodes is not sufficiently low at current less than 2 to 5 mA to ensure $E \approx 100\%$, the current drain from the source is hence of the order of 8 to 10 mA or higher, on the basis of approximately equal currents through Z_1 , Z_2 and Z_4 , the current through Z_3 (and R_1) being approximately double this value and half the total current from the supply.

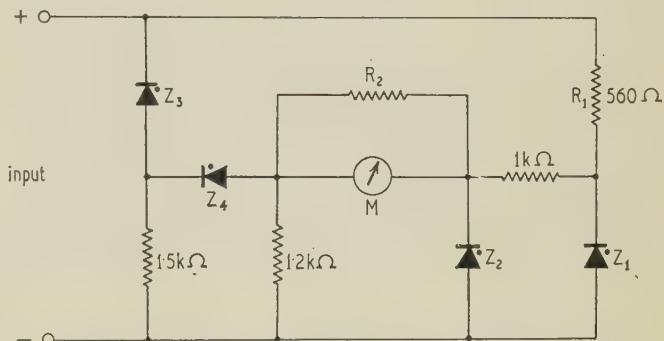
Hence given the approximate values for these currents, appropriate Zener diodes can be selected, with suitable dropping resistors, on the basis of Ohm's law, Eqn (1), and the fact that

$$V_{z1} \approx V_{z2} + V_{z4}$$

the actual performance is affected only to a second order

by the actual component values selected. If R_1 is made variable the system may be adjusted to give zero meter reading for a selected input voltage. The sensitivity can similarly be adjusted to give a selected full scale deflection by an appropriate meter shunt R_2 .

The numerical values given in the Figure illustrate the general design of a typical unit. The centre zero reading



Circuit diagram of a suppressed zero voltmeter using Zener diodes. Centre zero 12.0 v, full scale deflection ± 50 mv.

Z_1 , Z_2 , Z_3 , Z_4 Zener diodes (Z_1 7 v at 5 mA, Z_2 and Z_4 3.6 v at 3 mA, Z_3 4.8 v at 8 mA).

M, multimeter using 50 μ A, 125 mv range.

R_1 , adjusted for centre zero of 12.0 v.

R_2 , adjusted for f.s.d. of ± 50 mv.

(All resistors wire wound, 1 w.)

of the multimeter M is 12.0 v, and the measuring range ± 50 mv using a 50 μ A, 125 mv range of a standard multimeter for M.

The true voltage reading is not established until approximately twenty seconds after connecting to the source to be measured, this being the time necessary for the diodes to reach their equilibrium temperature. To a first order thermal drifts in the diodes are compensated, and could be reduced by a careful selection of temperature coefficients of both diodes and resistances in the unit. For temperature changes of ± 10 deg C the zero of the voltmeter of the Figure changes by approximately ± 4 mv. However, in most applications measurements are made of differential changes in voltage, and this stability is more than adequate. If necessary, a zero reset control may be incorporated using a variable resistance shunting R_1 .

Simple bridge for the direct measurement of temperature differences

by M. C. GODIN, B.Sc., Ventilation Department, Rand Mines Ltd., Johannesburg, South Africa

MS. received 20th February 1961, in revised form 14th April 1961

Abstract. This note describes a sensitive thermometer, which measures temperature differences directly. The circuit is a simple Wheatstone bridge with thermistors as sensing elements. By choosing the resistances in a certain ratio to each other, equal temperature differences give galvanometer currents equal to within 0.6% of each other, for an absolute temperature change of 6 deg C.

Introduction

Thermistors, with their large temperature coefficients, are suitable for many types of temperature measurement. The most obvious way to measure temperature differences with them is to incorporate two identical thermistors in a Wheatstone bridge. If this is done indiscriminately the linearity of the galvanometer current with respect to the temperature difference is poor, and the sensitivity of the instrument varies with the absolute temperature. Both these faults can be largely eliminated by choosing the resistances in a certain ratio to each other.

Theory

The resistance of a thermistor to a first approximation, is given by $Ae^{B/T}$, where A and B are constants, T is the absolute temperature.

In the circuit shown in Fig. 1

$$g = \frac{V(QR - PS)}{PQR + PQS + PRS + QRS + G(P + R)(Q + S)} \quad (1)$$

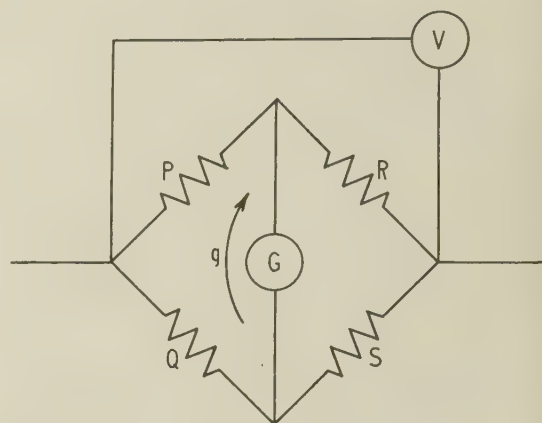


Fig. 1. Basic circuit V , voltage across the bridge; g , galvanometer current; G, P, Q, R, S , resistance values.

If R and S are two identical thermistors, S being at a temperature ΔT higher than R , and P is equal to Q ($R = Ae^{B/T}$, $S = Ae^{B/(T+\Delta T)}$, $P = Q$) Eqn (1) becomes

$$g = \frac{VP(R - S)}{P^2(R + S) + 2PRS + G(P + R)(P + S)}$$

expanding

$$g = \frac{V \left\{ \left[\frac{B\Delta T}{T(T + \Delta T)} \right] \frac{1}{1!} + \left[\frac{B\Delta T}{T(T + \Delta T)} \right]^2 \frac{1}{2!} + \dots + \left[\frac{B\Delta T}{T(T + \Delta T)} \right]^n \frac{1}{n!} + \dots \right\}}{P(1 + e^{B\Delta T/(T+\Delta T)T}) + 2Ae^{B/T} + \frac{G(P + Ae^{B/T})(P + Ae^{B/(T+\Delta T)})}{P \cdot Ae^{B/(T+\Delta T)}}$$

As ΔT tends to zero

$$g = \frac{VB\Delta TPAe^{B/T}}{T^2[2P^2Ae^{B/T} + 2P(Ae^{B/T})^2 + G(P + Ae^{B/T})^2]}$$

and keeping ΔT constant and differentiating g with respect to T

$$\frac{dg}{dT} = \frac{-VB\Delta TPR[P^2(4RT + GB + 2GT) + P(4R^2T - 2R^2B + 4GRT) + (2GR^2T - GR^2B)]}{T^4[2P^2R + 2PR^2 + G(P + R)^2]^2}$$

$$\frac{dg}{dT} = 0$$

when

$$P = \frac{R^2(B - 2T) - 2GRT + [R^4(B - 2T)^2 + G^2R^2B^2]^{1/2}}{4RT + G(B + 2T)}$$

If the thermometer is to be used at a temperature of about $T_1^\circ K$ then P must be chosen in accordance with (6), R being the resistance of a thermistor at this temperature. At $T_1^\circ K$

the instrument is most insensitive to small changes in absolute temperature.

From (2) differentiating g twice with respect to ΔT

$$\frac{V}{\sqrt{2}} = -VSPB(P + R)(2PR + GP + GR)$$

$$\begin{aligned} & \{P^2[RB - SB + GB + (2R + 2S + 2G)(T + \Delta T)] \\ & + P[GRB - GSB - 2RSB + (2GR + 2GS + 4RS)(T + \Delta T)] \\ & + [2GRS(T + \Delta T) - GRSB]\} \\ & \times \frac{1}{(T + \Delta T)^4(P^2R + P^2S + 2PRS + GP^2 + GPR + GPS + GRS)^3} \end{aligned} \quad (7)$$

When ΔT equals zero thus making S equal to R , $d^2g/d\Delta T^2$ comes zero when

$$\frac{R^2(B - 2T) - 2GRT + [R^4(B - 2T)^2 + G^2R^2B^2]^{1/2}}{4RT + G(B + 2T)} \quad (8)$$

By a happy coincidence, this is identical to (6). This means that there is a point of inflection at the point where $d^2g/d\Delta T^2 = 0$, when $T = T_1^\circ \text{K}$. In other words, when the thermometer is most insensitive to the absolute temperature, it is also most linear with respect to the temperature difference.

Typical characteristics

The figures quoted were calculated from Eqn (3), using resistance values based on an instrument constructed. $R = 6800 \Omega$, $A = 0.11 \Omega$, $G = 530 \Omega$, $B = 3050^\circ \text{K}$, $dT = 0$ when $T = 302^\circ \text{K}$.

Table 1. Variation of sensitivity with absolute temperature ($\Delta T = 0$)

$T(^{\circ} \text{K})$	280	285	290	296	300	302	305	310	313	315	320
$\frac{g10^6}{V\Delta T}$	1.412	1.468	1.512	1.541	1.549	1.550	1.549	1.534	1.518	1.510	1.479

It can be seen that a change in the absolute temperature of 2°C from the temperature producing maximum sensitivity (302°K), produces a change in sensitivity of less than 0.1%.

Table 2. Variation of linearity with absolute temperature

	$g10^6/V\Delta T$			
$T(^{\circ} \text{C})$	$T = 290^\circ \text{K}$	$T = 300^\circ \text{K}$	$T = 302^\circ \text{K}$	$T = 313^\circ \text{K}$
0	1.512	1.549	1.550	1.518
1	1.513	1.550	1.549	1.517
2	1.515	1.550	1.548	1.515
3	1.517	1.550	1.547	1.512
4	1.521	1.549	1.546	1.508

It is clear that greatest linearity is obtained at an absolute temperature slightly below that which produces maximum sensitivity, since the point of inflection then occurs at some positive value of ΔT .

Construction and operation

Fixed resistances M and N have resistance values similar to the thermistors under operating conditions. (M and N are necessary to adjust the voltage and are not equal.) The circuit is capable of putting either the thermistors or M and N into the circuit. The calibration of the thermometer is done in terms of the resistances in the circuit, and has nothing to do with the sensitivity of the galvanometer (in fact the galvanometer can be replaced by a completely different one, one with the same resistance, and the calibration remains unaltered).

The calibration procedure is to determine what ΔT produces the same galvanometer current as M and N . Two

water-baths are needed. The thermistors are placed next to each other in the same bath and the galvanometer current is brought to zero by adjusting X and Y . They are then placed in separate baths, which are at different temperatures, and the galvanometer deflection is noted. The thermistors are replaced by M and N and the deflection is again noted. For example, let us assume that the temperatures of the baths differed by 3.58°C , and that this produced a galvanometer deflection of 197 divisions. With M and N in the circuit the deflection was 153 divisions. At any voltage M and N will then produce the same deflection as a ΔT of $3.58 \times 153/197$, or 2.78°C .

Before using the thermometer the voltage must be adjusted. If the galvanometer has 300 divisions and it is desired that this should represent a ΔT of 3°C , then M and N are put into the circuit and V is adjusted by means of J until the galvanometer deflection is 278 divisions. If the thermistors

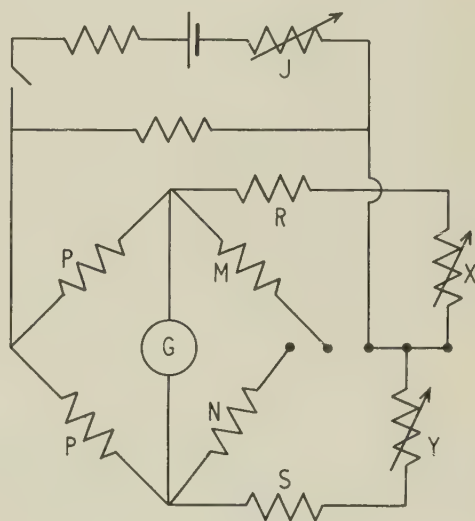


Fig. 2. Circuit diagram.

are now put back into the circuit, temperature differences can be read directly off the galvanometer (e.g. 162 divisions indicates a ΔT of 1.62°C).

Sensitivity can be increased by increasing the voltage, provided this does not cause appreciable heating in the thermistors. Once this limit has been reached, a further increase in sensitivity can be achieved by using a more sensitive galvanometer, or a direct current amplifier and related equipment, in place of the galvanometer. This latter method would be extremely sensitive.

Design of magnetoresistance elements

by D. H. ROBERTS, The Plessey Company Ltd., Caswell Research Laboratories, Towcester, Northants.

MS. received 23rd February 1961

If a filament of single crystal semiconductor is placed in a magnetic field, its resistance increases because of the decrease in the effective carrier mobility. It has been suggested (Ross and Saker 1956) that use could be made of this phenomenon for measuring linear displacement by observing the change in resistance of a suitably shaped specimen when moved in a magnetic field gradient. More recently an instrument has been described by Hilsum (1958) in which without amplification an output of 1 mv is obtained for a movement of 20 microns. Using an a.c. system with a simple transistor amplifier a displacement of 10 Å can be detected.

It is the purpose of this note to consider the ideal geometry of specimen to be used for this purpose, and hence to suggest how the performance of the instrument described by Hilsum might be improved. In practice, the use of a bridge-shaped specimen is ideal in order to minimize spurious output voltages due to the temperature coefficient of resistance of the individual arms. However, we can most easily discuss the ideal shape of each bridge arm, and the method of moving the magnet, with reference to a simple rectangular specimen of thickness t , distance between electrodes L , and width W . Let us now assume that there is a certain maximum permissible dissipation given by $D/2$ w/cm², and that the sample conductivity is given by σ_0 and σ_B (resistivity ρ_0 and ρ_B) in zero field and B oersteds respectively.

If we consider a specimen partially immersed in the magnetic field then there are two obvious configurations, indicated in Fig. 1(a) and (b).

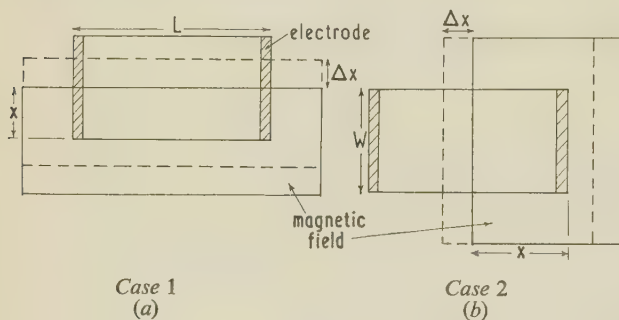


Fig. 1.

Case 1. The fractional change in conductance for displacement Δx relative to the magnetic field is given by

$$\frac{\Delta\chi}{\chi} = \frac{\Delta x \Delta\sigma}{x\sigma_B + (W-x)\sigma_0} \quad (1)$$

where $\Delta\sigma = \sigma_0 - \sigma_B$. Inspection shows that since $\sigma_0 > \sigma_B$, $\Delta\chi/\chi$ will be a maximum when $W-x$ is small. Hence

$$\frac{\Delta\chi}{\chi} = \frac{\Delta x \Delta\sigma}{W \sigma_B} \quad (2)$$

Case 2. The fractional change in resistance for displacement Δx is now given by

$$\frac{\Delta R}{R} = \frac{\Delta x \Delta\rho}{x\rho_B + (L-x)\rho_0} \quad (3)$$

where $\Delta\rho = \rho_B - \rho_0$. In this case, since $\rho_B > \rho_0$, $\Delta R/R$ a maximum when $L \gg x$.

Hence

$$\frac{\Delta R}{R} = \frac{\Delta x \Delta\rho}{L \rho_0}$$

Since for small displacements $\Delta\chi < \chi$ and $\Delta R < R$ we can write for the signal voltage ΔV .

Case 1.

$$\Delta V_1 = V_1 \frac{\Delta x \Delta\sigma}{W \sigma_B}$$

Case 2.

$$\Delta V_2 = V_2 \frac{\Delta x \Delta\rho}{L \rho_0}$$

where V_1 and V_2 are the applied voltages.

It can easily be shown that $\Delta\sigma/\sigma_B = \Delta\rho/\rho_0$ so that we can write

$$\frac{\Delta V_1}{\Delta V_2} = \frac{V_1 L}{V_2 W}$$

if one assumes $\Delta\rho$ the same in both cases, which is not necessarily so because of the different boundary conditions. Now, since V_1 and V_2 are limited by dissipation

$$(V_1^2)_{\max} = \frac{DL^2}{\sigma_B t}$$

$$(V_2^2)_{\max} = \frac{DL^2}{\sigma_0 t}$$

Inserting (8) and (9) into (7) we can write

$$\left(\frac{\Delta V_1}{\Delta V_2}\right)_{\max} = \left(\frac{\sigma_0}{\sigma_B}\right)^{\frac{1}{2}} \frac{L}{W}$$

Since $\Delta V \propto V \propto L$ in either case, and $\sigma_0 > \sigma_B$ we can see that the highest signal voltage will be achieved by having $L \gg W$ and moving the sample relative to the magnetic field as indicated in Fig. 1(a). This is the reverse to the method shown in Fig. 1(b) that has been used previously. For maximum sensitivity, $W-x = \delta$ must be kept small, but the output is then linear only over the small displacement δ .

At first sight the use of such an aspect ratio will degrade the coefficient of magnetoresistance in so far as the Corbino effect will be negligible. It has, however, been shown by Welker (1955) that if a long, thin specimen is divided into a number of short, wide specimens by means of evaporated metal stripes, then the stripes serve to short-circuit the Hall voltage and hence to increase the magnetoresistance effect.

If suitably doped p-type indium antimonide is used, then the conductivity is less than that of intrinsic material so that the maximum applied voltage can be increased. Furthermore, if a long thin specimen is used without shorting bars then the magnetoresistance effect is highest in p-type material (by a factor of 3 for 5×10^{16} acceptors/cm³ in 10 000 oersteds—see Hilsum (1958)).

In practice one of the difficulties associated with the construction of magnetoresistance devices is that of achieving low contact resistance. Since this is only of importance relative to the bulk resistance one can see that a long thin specimen is again to be favoured, and also that p-type material is likely to be more satisfactory than n-type providing the actual contact resistance per unit length of electrode the same for all material.

As a result of the above considerations it is suggested, therefore, that the optimum design of magnetoresistance element is not that used, for example, by Hilsun, but that the following rules should be applied:

(i) The best possible performance at a given temperature will be achieved by using a long narrow specimen fabricated out of intrinsic material with evaporated shorting bars as described by Welker.

(ii) If it is undesirable to apply such a pattern of electrodes on a long thin specimen using p-type material is the most favourable, the doping level in the p-type material being in the region of 6×10^{16} acceptors/cm³.

(iii) It may be better to use p-type material in any case in order to achieve improved temperature stability. In that case the shorting bars are likely to become redundant because of the fall in the Corbino effect with increased acceptor concentration (Hilsun 1958).

Acknowledgments

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On making thin 'Vinylite' V.Y.N.S. film

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(S. received 6th February 1961, in revised form 21st March 1961)

The production of a thin film of material of low atomic number is essential in many applications of β -ray spectroscopy and in absolute counting experiments. In the past upon, collodion, formvar, nylon, and cellulose nitrate or acetate have been successfully employed (Backus 1945, Brown *et al.* 1948, Fry and Overman 1948, Heller *et al.* 1950, Leissner and Byrne 1952, Revell and Agar 1955, Chen 1960). Generally speaking, these materials all suffer from such defects as attack by acids, alkalis, organic solvents or other chemicals which to some extent limits their application. More recently (Pate and Yaffe 1955), a new material was introduced, viz. 'Vinylite' V.Y.N.S. resin (a polyvinylchloride-acetate copolymer manufactured by the Bakelite Co.), which is remarkably strong and resistant to acids alkalis and to most organic solvents. It is soluble in cyclohexanone.

The technique of producing a film by pipetting a drop of the material in solution on to a water surface (Backus 1945) which works well for most other materials, fails with this resin as does the method of casting films on a glass slide (Fry and Overman 1948). A more elaborate technique has been described (Pate and Yaffe 1955) in which thin films of 'Vinylite' V.Y.N.S. resin are made by placing a small quantity of a cyclohexanone solution of the plastic in the space between a cylindrical rod and the side of a tray containing water. The rod is then drawn quickly over the water surface and a thin film spreads behind it. In our experience, such films are frequently wrinkled, and flat, smooth areas are unable to show striations and other signs of non-uniform thickness, so an attempt was made to find a different method of producing these films.

The following technique consistently and easily produces

smooth strips of film whose thickness varies only slowly along the entire length of the strip and is nearly constant across the width. It is possible that this method has been used in the past to produce films of other organic materials but we have not found a reference to this.

A little 'Vinylite' V.Y.N.S. solution is spread evenly along the edge of a glass plate (thin window glass serves very well). A large developing dish is filled with water. The coated edge of the glass plate is then touched to the water surface by rocking the plate on the side of the developing dish so that the entire edge meets the water at the same moment. A sheet of film whose width is approximately the same as that of the plate is drawn by surface tension across the water surface.

The film thickness attained depends somewhat on the strength of the 'Vinylite' V.Y.N.S. solution, weak solutions yielding thinner films as is to be expected. Films averaging less than $10 \mu\text{g}/\text{cm}^2$ can be readily produced from a solution 5 parts cyclohexanone to 1 part 'Vinylite' V.Y.N.S. resin by volume. It is our experience that better films are produced on cold (10°C) water than on warm (45°C) and that it is advisable to change the water frequently if many films are required, for the quality deteriorates with increasing concentrations of solvent in the water.

To remove the film from the water surface we raise a wire ring until it is observed that the film is in contact with the entire perimeter of the ring, then run a small paint brush moistened with cyclohexanone round the outside of the ring. This separates the film on the ring from the rest of the sheet and it can be lifted off the water surface with a rolling motion so that one edge of the film separates before the other. This

reduces the tendency of the film to tear on separation from the water surface. From one large sheet a number of smaller areas of film can be removed.

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A 'black-box' frequency stabilizer for an electron-spin-resonance spectrometer

by W. A. GAMBLING, B.Sc., Ph.D., and T. H. WILMSHURST, B.Sc.(Eng.), Ph.D., Department of Electronics, University of Southampton

MS. received 21st April 1961

In many ways it is desirable when operating an electron-spin-resonance spectrometer, that the signal klystron should be accurately tuned to the resonant frequency of the spectrometer cavity. Several electronic-type systems have been developed which achieve this stabilization and the main advantage of the following arrangement, shown in Fig. 1, is that it can be incorporated into most existing spectrometers without the necessity for interfering with the existing electronic circuitry.

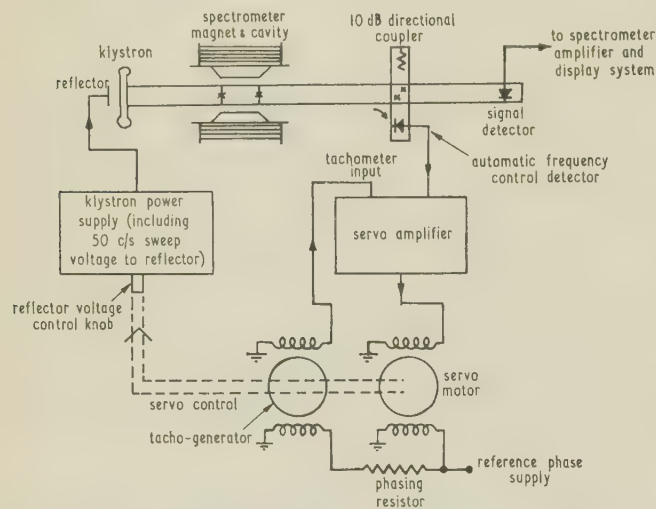


Fig. 1. Servo-controlled klystron frequency stabilizer for an electron-spin-resonance spectrometer.

A small 50 c/s sweep voltage is applied to the reflector of the klystron, using the sweep supply normally included in most spectrometers for initial setting up. This produces slight frequency modulation and if the klystron is not operating at the cavity resonant frequency then, due to the shape of its Q -curve, the cavity acts as a discriminator partially converting the frequency modulation to amplitude modulation. The depth of amplitude modulation is proportional to the slope of the Q -curve and is therefore zero at resonance and reappears with opposite phase when the frequency error changes sign. The resulting 50 c/s component at the automatic frequency control detector, if

amplified and fed to a servo-motor, can be used to correct the reflector voltage control knob on the klystron power supply and so ensure that the klystron is tuned to the peak of the cavity Q -curve.

As with all stabilizing loops it is important, if hunting is to be avoided, that no elements should introduce a time-lag within the loop. For this reason an efficient tachometer damping system should be used to counteract the effects of motor inertia. In practice an upper frequency response of approximately 5 c/s has been achieved in this way and was found to be quite sufficient.

Often C.R. networks are built into the klystron power supply thus introducing a delay in the response of the reflector voltage to a manual displacement of the control knob. As indicated above hunting may result and, if so, the most complete solution is to use the alternative system shown in Fig. 2. Here a potentiometer is connected in series with

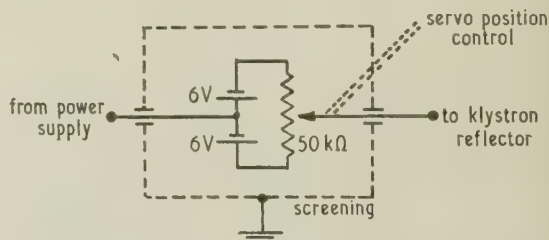


Fig. 2. Alternative system for controlling reflector voltage of klystron.

the klystron reflector and the spindle is coupled to the servo gearbox via an insulating coupler. Even this step does not involve breaking into the klystron power supply unit and difficulty should be encountered with low- or high-voltage klystrons.

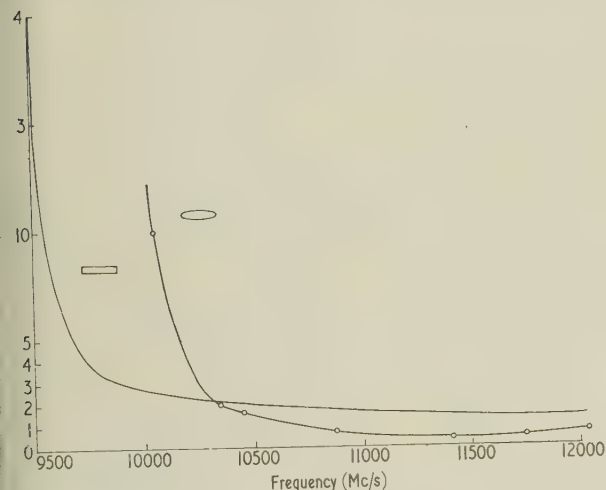
It has been found in practice that this system adequately corrects for the effects of long term klystron drift and short term room temperature changes in both reflection and transmission cavity spectrometers. It has also been found suitable for locking the klystron to an external reference cavity and again no modification of the existing electronic circuitry is involved.

Simple approach to cryogenic wave-guide

D. K. MILNE, A.S.T.C., Commonwealth Scientific and Industrial Research Organization, Radiophysics Laboratory, Sydney, Australia

S. received 5th April 1961

A low thermal conductivity wave-guide is often required to microwave apparatus immersed in liquefied gases. It is usual to fabricate this wave-guide from thin-walled stainless steel, nickel silver or German silver tubes, which are readily available. A method for drawing this tube into a rectangular section has been described (Caistor, Frey and Hopper 1959) in which the tubing is annealed in a vacuum furnace and passed several times between a mandrel and die, with annealings between passes, until the final rectangular shape is produced. However, if one is prepared to sacrifice band-



width, then there are advantages in using a 'quasi-elliptical' guide in that, as well as having a definite polarization (unlike circular guide) it is more easily constructed, is mechanically stronger and has a lower minimum attenuation than a rectangular guide drawn from the same tube (Southworth 1950).

This quasi-elliptical guide is constructed by inserting a

rectangular mandrel, which can in most cases be merely a length of stock steel or brass bar, into the tube and rolling the tube down on to the flat faces of the mandrel using a set of plumber's rollers. A mandrel and a tube size are selected by reference to a rectangular wave-guide of suitable attenuation and somewhat lower cut-off frequency than the lowest frequency transmitted. The tube should have the same periphery as this rectangular guide. The mandrel should be approximately the same minor dimension and about three-quarters the major dimension of the rectangular guide. This mandrel can then be pushed without much effort into the full length of the tube ready for rolling. A rectangular forming plug is driven into the ends of sections required to mate with rectangular guide, the inherent length of taper so produced giving a satisfactory elliptical to rectangular transition. This guide is extremely reproducible and, unlike the guides produced by the processes described elsewhere, the length is only limited by the available tube length. It is produced without the delay and cost of preparing dies. There is no oxide scale to remove and the stronger elliptical section of unannealed material gives less change in attenuation when the system is evacuated.

In the author's apparatus an operating region of from 10 500 to 12 000 Mc/s was required. A rectangular guide of $\frac{5}{8}$ in. $\times$ $\frac{1}{8}$ in. was suitable, and so 12 mm diameter $\times$ 0.3 mm wall thickness German silver tube was rolled on to a $\frac{1}{2}$ in. $\times$ $\frac{1}{8}$ in. mild steel bar, giving a quasi-elliptical guide of $\frac{5}{8}$ in. $\times$ $\frac{3}{32}$ in. major and minor axes. The electrical characteristics were measured and are compared in the Figure with the attenuation calculated for $\frac{5}{8}$ in. $\times$ $\frac{1}{8}$ in. German silver rectangular guide.

References

- CAISTOR, A., FREY, S. T., and HOPPER, W. C., 1959, *J. Sci. Instrum.*, **36**, 144.
SOUTHWORTH, G., 1950, *Principles and Application of Wave-voltage Transmission*, p. 193 (Princeton, N.J.: D. Van Nostrand).

Simple and cheap power supply for a Pointolite lamp

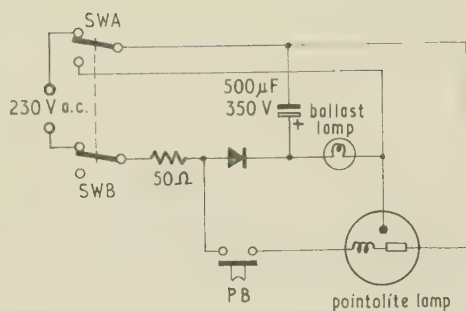
R. E. HAYES, M.Sc., Ph.D., and A. R. V. ROBERTS, B.Sc., The Plessey Co. Ltd., Roke Manor, Romsey, Hants.

S. received 29th March 1961

The auxiliary equipment for starting and running laboratory charge lamps from the a.c. mains frequently costs many times more than the lamp itself. It is also often unnecessarily bulky as large resistance loads may be used and these dissipate more power than the lamp itself. Very simple circuitry may be evolved using an ordinary

tungsten lamp to provide the constant current source required to stabilize the discharge. Its resistance-temperature characteristic will give additional current stabilization against supply voltage variations.

The circuit illustrated was used to operate a 30 c.p. d.c. Pointolite lamp. This lamp is started by a current of 4.5 A



passed through its ionizer filament for about one second and is thereafter run with a direct current of 0.45 A, which drops about 46 v across the discharge.

In our circuit a $50\ \Omega$ 30 w resistor is used to limit ionizer current supplied via the push-button PB and, in this current only heats up the ionizer filament, raw a.c. is used. The thermal capacity of the resistor is more than adequate to accept this high loading for the period required for starting. A silicon diode and a $500\ \mu\text{F}$ electrolytic capacitor provide d.c. for normal running with the $50\ \Omega$ resistor now serving as a surge limiter. This gives a low ripple current through the lamp. The running current is controlled at 0.45 A by a 160 v tungsten ballast lamp. This lamp is readily available as it is normally used to regulate fluorescent lights. A double pole two-way switch is used as an ON/OFF switch and also to discharge the smoothing capacitor via the ballast lamp, when the unit is switched off.

The total cost of the components is estimated at about half that of the pointolite lamp. The power supply has been used without trouble for a considerable period.

Rigid metal-glass vacuum systems. Strain relief and separation

by T. G. CORK, Mullard Research Laboratories, Salfords, Redhill, Surrey

MS. received 15th March 1961

Two difficulties arise in a glass vacuum system which is fixed rigidly at two points.

Firstly, there is a risk of breakage if the whole system is heated; this is due to expansion of the glass between the two fixed components.

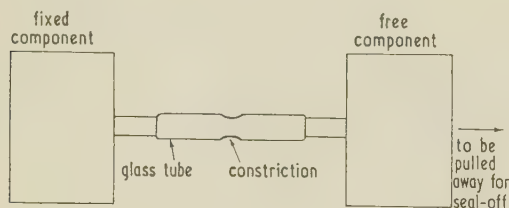


Fig. 1. Conventional seal-off of free component.

Secondly, it is very difficult to separate two fixed components in the system by a normal seal-off method, because the components cannot be pulled apart.

These difficulties can be overcome by inserting a loop with two constrictions in the glass-ware between the two fixed

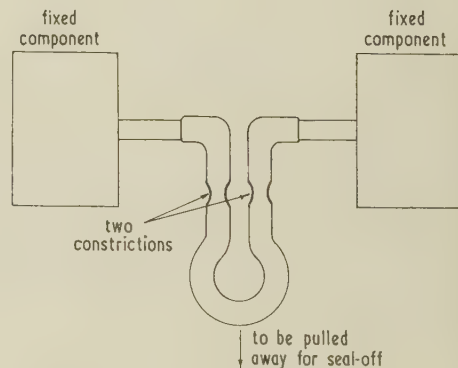
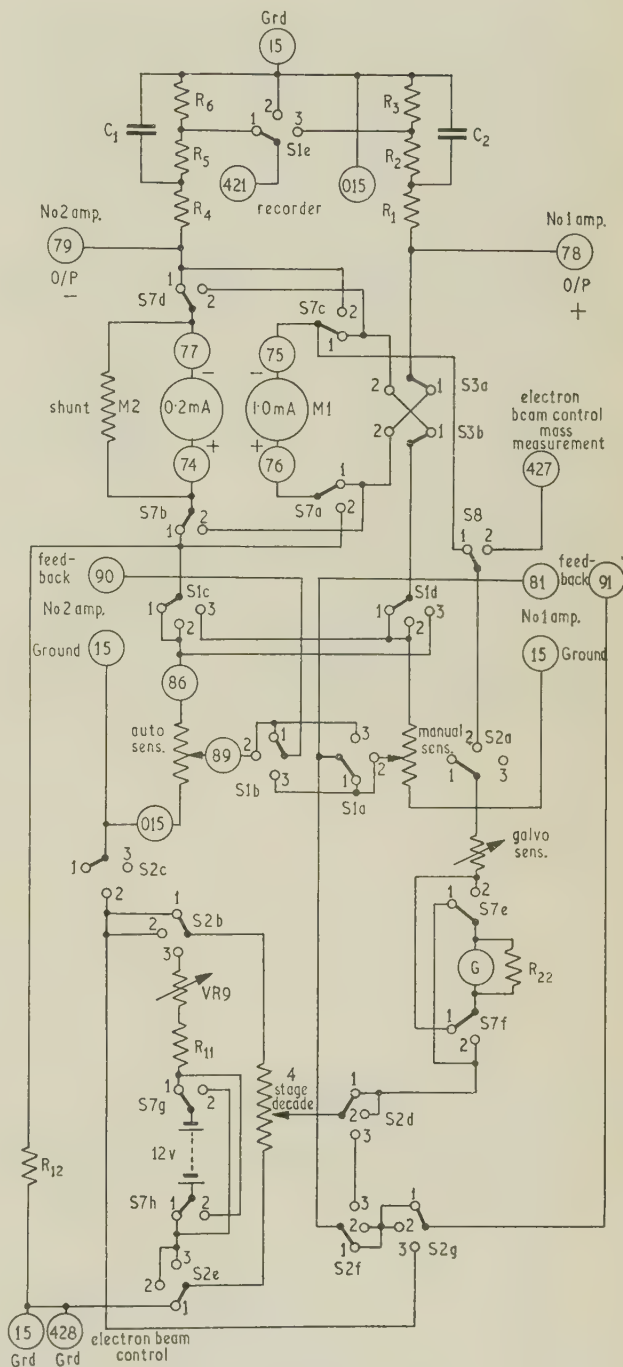


Fig. 2. Seal-off between two fixed components.

points, as shown in the accompanying diagrams. The loop introduces a resilience which absorbs strains in the glassware caused by heating, and seal-off can be effected by heating the two constrictions simultaneously and pulling away the loop.

S. received 28th March 1961

wish to thank I.C.I. Ltd. for a Research Fellowship: M.S.2 on which these modifications have been made is used for research into gaseous free radicals under grants from the Department of Scientific and Industrial Research and Esso Research Ltd., to Dr. J. W. Linnett.



S1 Recorder Selector: 1, No. 2 ampl.; 2, Off; 3, No. 1 ampl.
S2 Operation Selector: 1, Off; 2, Null; 3, Calibrate.
S3 No. 1 ampl. output meter polarity: 1, Positive; 2, Negative.
S7 Meter Reversal: 1, Normal; 2, Change over.
S8 Null Signal Selector: 1, Amplifiers; 2, Mass measurement.

Transistorized water-level meter

by R. R. VIERHOUT, Dept. of Medical Physics, R.C. University, Nijmegen, The Netherlands

MS. received 7th April 1961

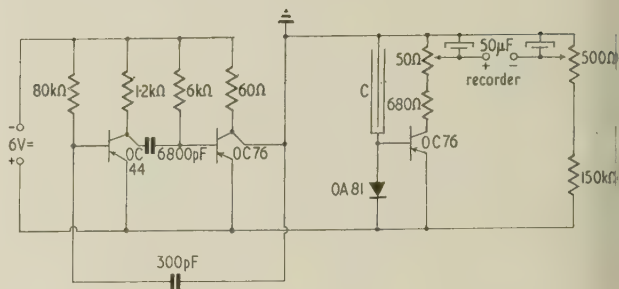
For the measurement of pressures which do not change rapidly a common water manometer is often used, but a continuous registration of the water level is sometimes required. This can be done fairly simply by an electrical method which is described below. This method can be used because the electrical conductivity of water can be made sufficiently great by the addition of a small amount of electrolyte.

A platinum wire is stretched along the axis of the glass tube of the water manometer. A thin copper foil is glued on the outer surface of the tube covering half of the circumference. The wire and the foil are the two electrodes of the capacitor C.

When the tube is filled with air a dielectric of glass and air in series fills the capacitor. If the tube between the wire and the foil is partly filled with water of good conductivity, then the capacity of C is increased. It increases linearly with the height of the water level. This effect is used for the measurement of the fluid level.

The Figure shows the electric circuit, consisting of a multivibrator which charges the capacitor C in the glass tube via the transistor with a positive charge during each cycle.

The voltage in the capacitor C is equal to the voltage amplitude of the multivibrator because the RC-time of C and the forward base-emitter resistance of the transistor are small in comparison with the multivibrator period. As the multivibrator has a constant amplitude the voltage on C is



also constant. Hence the positive charge on the capacitor C is proportional to C and in the other half of the cycle when the diode is conducting, the capacitor is completely discharged because the RC-time of the capacitor and diode is much smaller than the multivibrator period.

When the capacitor C charges, a collector current flows which charges the capacitor of $50\mu\text{F}$ at the positive side of the recorder, to a positive voltage. A bleeder to the negative side of the recorder gives a balance voltage to adjust the zero to a desired level. With the potentiometer at the positive side of the recorder the amplification factor can be varied. The output is linear with C within 1% as long as $C < 50\text{ pF}$, if a medium power transistor and a low collector impedance are used.

Aluminium bakeable vacuum seal

Bakeable vacuum seal has been developed in this laboratory using an aluminium wire gasket which flows under high compression during baking and by frictional adhesion adheres to the flange faces (Holden, Holland and Laurenson 1959, Elsworth, Holland and Laurenson 1960). The cemented joint thus formed can easily be broken when desired. Data are given by Elsworth, Holland and Laurenson (1960) on the strength of the aluminium seal as a function of the compression force applied during forming and baking the seal. The measurements were made with the compression force kept constant with a hydraulic ram. In practice one uses flanged flanges and relies on the seal being compressed during mating by the tension in the clamping bolts, but the tension of the bolts is gradually relieved as the aluminium wire flows. In spite of this satisfactory seals have repeatedly been made between flanges of up to 4 inches in diameter using initially the compression forces given in the reports.

Recently we have had experience in making bakeable seals between 15 in. diameter flanges and it has been found that failure can sometimes occur. The reasons for this are not completely clear, but it has been partly attributed to the bolt tension being relieved before adequate frictional adhesion has occurred. Further, the compression force due to each bolt may not be identical when the bolts are tightened to similar torques because of variations in the transmission section. Leaks may also occur in large diameter bakeable seals because of the increased hazard of dust particles settling between the mating surfaces.

Leaving aside the latter problem, most of the difficulties

in ensuring continuous and uniform compression during baking can be overcome by using 'Belville' or conical spring washers under the heads of the clamping bolts. The Belville type washer must be chosen to withstand the compression to be applied to the wire and deflect as the wire flows. Conical washers made of chromium-molybdenum steel (T171) by Schnorr* (Germany) will withstand baking temperatures of up to 400° C. Successful seals have been repeatedly made between 15 in. diameter flanges clamped with sixteen $\frac{1}{2}$ in. B.S.F. stainless steel bolts fitted with Schnorr washers.

It was intended to publish a more thorough account of the use of the Belville washer but a short report (*Le Vide* 1961) has just appeared which shows that such washers have also been used by others for overcoming preferential expansion in more conventional types of bakeable seal. The washer has been in use in this laboratory for some months and this information will therefore be of immediate value to anyone contemplating the use of cemented aluminium gaskets in large diameter flanges.

Vacuum Deposition Research Division, L. HOLLAND.
Edwards High Vacuum Ltd.
Manor Royal,
Crawley, Sussex.
16th June 1961

HOLDEN, J. T., HOLLAND, L., and LAURENSEN, L., 1959,
J. Sci. Instrum., **36**, 281.

ELSWORTH, L., HOLLAND, L., and LAURENSEN, L., 1960,
J. Sci. Instrum., **37**, 449.

Le Vide, 1961, **15**, 23.

* International Engineering Concessionaires Ltd.

NOTES AND NEWS

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep her informed of their new or improved products. The Institute of Physics and The Physical Society assumes no responsibility for the statements given below; information for these has been taken from literature supplied.

New photocell for infra-red applications. Mullard Ltd., Mullard House, Torrington Place, London, W.C.1.

The ORP13 photoconductive cell has a sensitive area of approximately 3 mm² of indium antimonide. It is attached to its own Dewar flask and is cooled by liquid nitrogen to 4° K, one filling of the flask being sufficient for 45 minutes' operation.

The spectral range of the ORP13 is from the visible to about 5.4 micrometres, peak sensitivity of 15 mv per micro-watt occurring at between 4.5 and 5 micrometres. The noise

equivalent power per unit bandwidth (1 c/s) is better than 1.3×10^{-11} watt, and this figure gives an area-normalized detectivity better than 1.3×10^{10} cm watt⁻¹. It is claimed that this detectivity is higher than that of any other cell yet commercially available covering the spectral range up to 5 micrometres.

Filter unit for liquids. Gelman Instrument Co., 106 North Main St., Chelsea, Michigan, U.S.A.

The filter consists of a porous plastic sheet, the sponge-like cavities of which trap all particles of 0.1 micron and above. The plastic sheet is housed in a metal container and supported by a sintered stainless-steel plate. The membrane filter is disposable. The filter holder is available in three models for working pressures of 50, 100 and 500 lb/in². It is available in a choice of stainless steel or nickel-plated bronze construction.

The filter may be used for such purposes as the filtration of

missile hydraulic fluids and fuels, beverage clarification and cold sterilization and water processing.

Compound for joining aluminium. Eutectic Welding Alloys Company, Ltd., North Feltham Trading Estate, Faggs Road, Feltham, Middx.

AutoChemic 990 is a paste compound which is claimed to give high strength, corrosion resistant joints on virtually all types of aluminium and aluminium alloys, and requires no finishing or after treatment. No filler alloy is needed and the compound is merely painted on where required. By indirectly heating the joint a series of chain-type reactions take place terminating in metallic reduction at the reaction temperature of 400° C.

990 is recommended by the manufacturers for all fine work such as wire and cable jointing, instrument parts, small wave guides, floats etc.

Transistorized XY plotting boards. Computer Systems, Inc., Culver Road, Monmouth Junction, New Jersey, U.S.A.

The single-arm MC-3301 30 in. $\times$ 30 in. plotting board accepts a pair of d.c. voltages and positions a writing pen in accordance with their magnitudes. The two-arm MC-3302 board accepts two pairs of input signals, and circuits are provided which permit simultaneous plotting by each arm and pen over the entire surface of the board. In both cases the board, which has a depth of 12 inches overall, may be mounted on a table or wall in any desired position from horizontal to vertical, or it may be installed on a console base, with or without an automatic tilting mechanism. It is claimed that the static accuracy is to $\pm 0.05\%$, the dynamic accuracy $\pm 0.05\%$ up to 10 in. s^{-1} and $\pm 0.07\%$ up to 16 in. s^{-1} . The maximum writing speed is 30 in. s^{-1} , and slewing speed 40 in. s^{-1} ; the accelerations of arm and pen assemblies are respectively 250 and 1000 in. s^{-2} .

The plotting surface, which is extremely rigid, consists of a laminated assembly formed by a plastic surface chosen specifically for its abrasion resistance, an electro-luminescent panel, and a honeycomb aluminium base. The electro-luminescent panel gives even glare-free backlighting of the plotting surface without heat generation, thus eliminating the drying-out of paper, and has a guaranteed life in excess of 10000 hours. Paper is held down on the board electro-mechanically and is gripped firmly even when the power to the board is off. Alternatively the paper is held down by a vacuum arrangement, which is equipped with a toggle valve to reverse the normal air flow, thereby clearing all vacuum apertures.

The board is fitted with all necessary power supplies, servo-amplifiers, and in the case of two-arm boards, an automatic interchange control unit. The power required by the servo-amplifiers and motors is generated internally. All electronic circuits are fully transistorized, and are mounted on plug-in assemblies. The arm and pen position feedback potentials are taken from fully enclosed multi-turn potentiometers which are coupled to the arm and pen drive mechanism. The card length of the potentiometers is greater than the plotting length of the board, to improve resolution and linearity, and the potentiometers provide electrical braking at the limits of the normal plotting surface to prevent the servos from driving into the mechanical stops at high velocities.

A control panel, which can be removed from the board and located remotely, provides independent controls for each

channel, arm or pen, consisting of: Parallax, Scale Factor, Board Clear, Calibrate and Input Ground. The parallax control permits location of the 0,0 point anywhere on the plotting surface. The scale factor control consists of an incremental and a vernier control pair, which together provide any sensitivity from 1.5 to 150 volts full scale. The board clearing controls permit clearing of the plotting surface by replacement of paper without alteration of the setting of any of the other controls. The calibration control allows the application of an internally or externally derived potential to the servo, so that the scale factor controls can be calibrated when the vernier section is in use. The input ground control allows the input to the servo to be grounded, so that the 0 point established with the parallax controls can be checked. Input isolation amplifiers are available to permit operation of the board from input sources of high or varying impedance. An expanded parallax input unit is also available which provides up to 10 board widths of parallax, so enabling the operator to place the plotting surface anywhere in a 300 $\times$ 300 inch square.

The pen or pens are controlled from the control panel and/or from remote controls. The pens are normally retracted and a circuit must be closed to lower them to the normal writing position. Pens are automatically lifted from the paper if maximum writing speed is exceeded, if the pens are arms are interchanging signals (in the case of the two-arm board), and if the power to the board is removed. Additional pen assemblies may be mounted on each arm, so that two colour plotting can be obtained, with choice of colour made from the control panel. In the case of two-arm boards, each curve may be plotted in one colour, the colours used by each arm being interchanged when the signals are interchanged in cross-over. Timing marker pens may also be added to the arms, with internal or external control and time mark generation.

Strain gauge accelerometer. Consolidated Electrodynamics Corporation, 360 Madre Villa, Pasadena, California, U.S.A.

The Type 4-202 is a linear unbonded strain gauge bi-directional accelerometer with a four-active arm spring-type sensing element. Damping is by viscous oil-shearing, and oil of very low viscosity is used so that temperature dependence of viscosity, and hence damping, is exceptionally small. The mass suspension is of non-pendulous type for very low cross axis sensitivity, and mechanical stops are incorporated to permit over-acceleration.

The instrument, which has external dimensions approximately 1 in. $\times$ 1 in. $\times$ 1 in. and weighs about 3 ounces, is available in eight standard acceleration ranges, from ± 5 to ± 500 g. The permissible static over-acceleration is 100% for the ± 5 g unit and 750 g for the ± 500 g unit. Response to acceleration applied perpendicular to the sensitive axis is less than 0.01 g/g for inputs of three times rated range in the case of units with ranges up to ± 50 g, and for inputs ± 150 g in the case of units with ranges above ± 50 g. The natural frequency ranges from about 300 c/s for the ± 5 g unit to 2900 c/s for the ± 500 g unit, and the damping is 0.7 ± 0.1 of critical at 77° F. The combined effects of non-linearity and hysteresis are less than $\pm 0.75\%$ of full-scale output.

The instruments are temperature compensated over the interval -65° F to 250° F. Within this interval both the thermal zero shift and the thermal coefficient of sensitivity are less than 0.01% of full range per deg F.

Membrane filter for analysis of micron sized contaminants. Gelman Instrument Co., Chelsea, Michigan.

The filter has been designed specifically to speed the counting and sizing of contaminant particles in air, liquids for military purposes, and other fluids. It is made of a thin microporous plastic material with controlled micron size pores.

In use, a known amount of liquid is filtered through the membrane which is then microscopically examined either by reflected or transmitted light. Both particle count and particle size can be determined in this manner.

The main disadvantage of this method in the past has been the difficulty of observing white and light coloured particles. This membrane filter is, however, available in a dark green colour against which both light and dark particles are clearly contrasted.

The filter has the further advantages of being flexible, strong, and easy to handle, thereby making it practical for use on a routine basis with semi-professional personnel.

Improved portable infra-red radiant heater. Harris Engineering Co. Ltd., London.

This heater, which uses liquified petroleum gas as its fuel, is a development of the standard Harris-Schwank infra-red gas heater manufactured for installation in a wide variety of space heating applications.

The operation is on a system in which the gas/air mixture is expelled evenly and without special blowers through a large number of small holes in the ceramic plaques which form the burner surface. The mixture is ignited on the surface of the ceramic and reaches a temperature of 900°C. A layer of metal gauze made of Incoloy D.S. alloy, manufactured by Henry Wiggin and Co. Ltd., Birmingham, is fitted approximately a quarter of an inch away from the ceramic over the whole face of the burner. The use of this gauze, which has a remarkably good heat dissipation, improves the radiant efficiency without any increase in fuel consumption.

A standard burner is made up of eight ceramic plaques which together give a radiant surface measuring nearly 100 in². The energy intensity of the infra-red radiation is between 6 and 9 kcal h⁻¹ cm⁻² of radiating surface or between 700 and 1050 Btu per hour. The maximum energy radiated between wavelengths of 1.5 to 4 microns.

Frequency/time standard. Hewlett-Packard, 1501 Page Mill Road, Palo Alto, California.

The Model 103 AR is a high stability, ± 5 parts in 10^{10} per day, frequency standard.

The circuitry is fully transistorized and the crystal standard is contained in a double oven. It is insensitive to load and is virtually unaffected by supply voltage variations.

The short term stability is better than 5 parts in 10^{10} averaged over 1 sec intervals.

Output frequencies are 1 Mc/s sine wave 1 volt r.m.s. into Ω 100 kc/s sine wave 1 volt r.m.s. into 50Ω 100 kc/s output for driving frequency divider and clock 0.5 volt r.m.s.

The frequency may be adjusted by a coarse control of approximately 1 part in 10^6 and front panel fine control of 10 parts in 10^{10} , with a digital indicator calibrated directly in parts in 10^{10} . The unit is rack mounted 5½ in. × 19 in. and 1 in. deep, net weight 17 lb. Power requirements are 100-250 volts d.c.

Transistorized multiplexer. Packard Bell Computer Corporation, 1905 Armacost Avenue, Los Angeles 25, California.

An expandable multiplexer for data acquisition and computing systems is available for switching from four to sixty-four channels. The multiplexer operates with a settling time of 20 microseconds and will scan a full complement of 64 channels in 50 microseconds. Designated Model EM-3 it includes a rack mounted case with integral power supply and provisions for plugging in cards containing the switch circuits, up to a maximum of 64. Indicator lights to represent the channel selected are located on the front panel.

Cross selection is accomplished by external signals to flip-flops in the multiplexer. These may be incremented as a counter to operate the EM-3 as a commutator.

Input and output limits are ± 10 volts with no inversion and the unit will drive a stable load impedance of 2500 ohms or greater. Internal noise is less than 1 millivolt. The unit operates from 115 volts a.c.

Transistorized power supplies. Invar Electronics Corp., 232 W. Washington Blvd., Pasadena, California.

A new dual range transistorized power supply Model TPA-36-18 provides 0-18 volts at 3 amps or 0-36 volts at 1.5 amps, the range being selected by a front panel switch. Regulation against mains variation is 10 millivolts on either range; load regulation is held to 5 millivolts max, and ripple is 0.3 millivolts r.m.s. max.

The unit includes circuits for complete short circuit protection and incorporates terminals for both remote programming and remote sensing. Two Model TPA-36-18's may be connected in either series or parallel.

The unit is of compact size being 5 in. high, 8½ in. wide and 14 in. deep. One or two units may be mounted in a specially designed 5½ in. × 19 in. rack panel.

Auto Analyser for on-stream silica phosphate analysis-control. Technicon Controls, Inc., Chauncey, New York.

The Auto Analyser is used for on-stream control of boiler phosphate feed and determination of silica content of the boiler.

Silica content down to fractional parts per million can be detected. The characteristic blue colour indicating silica concentration is developed in the stream. Colour intensity is measured in a flow-type colorimeter, and its value is plotted continuously on a strip chart recorder. Continuous records can also be provided of trace quantities of copper, iron, phosphate, hardness, chloride and other materials present in the steam water cycle. The proportioning pump can handle as many as eight reagents simultaneously with delivery rates from 0.32 to 3.5 ml. per minute.

The Analyser can also be used to regulate blowdown and locate trouble spots in the system such as condenser leakage.

Modular construction of the various units, sampling, metering, mixing, reaction and analysis permits complete flexibility in arrangement for plant or laboratory use.

Rotary viscometer. Gebruder Haake, K.G. Berlin-Steglitz, Siemensstrasse 27.

The principle of the rotary viscometer is that a rotor spins at a known rate while immersed in the test substance, and the torque which varies with the viscosity is measured by

means of an electric dynamometer. The results are read directly on an indicating meter or are recorded. The measuring current can also be utilized for control and for regulating purposes. Measurements are based either on the Couette system where the inner cylinder rotates or on the Plate-cone system where there is a rotating cone. In special cases different rotors, of various shapes, e.g. propeller, can be used. The advantages of this particular viscometer are (1) large measuring range: viscosities, from 0.5 cP to $4 \times 10^9 \text{ cP}$, shear stress $10^{-10} \text{ dyn cm}^{-2}$, and shear rate 10^{-2} – 10^4 sec^{-1} ; (2) large range of temperature: -30°C to 150°C , and in special cases, -60°C to 2000°C ; (3) exact duplication of experimental conditions, and adaptation to different problems and special conditions; (4) rapid determination of viscosity–stress curves; (5) direct reading.

The instrument consists of a control instrument of dimensions $17 \text{ in.} \times 17 \text{ in.} \times 11 \text{ in.}$; and the viscometer itself, dimensions roughly twice the height and diameter approximately 4 in.

Automatic filling machine. Shandon Scientific Company Ltd., 6 Cromwell Place, London, S.W.7.

The 'Filamatic' automatic filling machine is designed to dispense pre-measured quantities of liquid, automatically and continuously, at a uniform selected speed. It may be fitted with inter-changeable glass or stainless steel syringes of 1, 3, 5, 10, 20, 30 or 50 ml. capacity, and special large models are available up to 1040 ml. capacity. Any free-flowing liquid can be handled, from water-thin solutions to light oils, polyester and epoxy resins, agar-gel, etc.

The machine incorporates an electronically-controlled variable-speed drive, which provides stepless speed control at constant torque regardless of load variations. The volume of liquid discharged at each stroke is regulated by an eccentric on the crankshaft, and is adjustable by micrometer control. The accuracy is to better than 1%. No maintenance is required beyond the replacement of two inexpensive thyratrons after 2500 hours operation, and the whole pumping mechanism is rapidly removed for cleaning or sterilizing.

Among factory-fitted extras available are: a synchronizing attachment which allows several machines to be 'ganged'; an automatic timer for re-cycling machines operating together with the synchronizing attachment; an electric counter; and a single shot attachment for use with a foot switch. Accessories which may be fitted after production include: a dual-valve attachment for increased accuracy; a non-drip delivery nozzle; an adaptor enabling Luer-Lok syringes (up to 10 ml) to be used; an all-glass filter attachment; a foot switch; and a fixed filling head which attaches to the machine housing.

Transistorized power supply units S.C. series. Mid-Eastern Electronics Inc., 32 Commerce Street, Springfield, New Jersey, U.S.A.

These units are built into dust proof anodised aluminium cases, measuring $4\frac{1}{16} \text{ in.} \times 6\frac{9}{16} \text{ in.} \times 6\frac{1}{2} \text{ in.}$, each unit being fitted with an octal plug for power input and output and four mounting studs.

There are eight models of the S.C. series giving from 12 v at 4 A to 40 v at 1.5 A. Both outputs are floating and either may be earthed.

Specifications for all units are: regulation 0.005% mains; 0.05% for 0 to full load charges; ripple less than 3 mv peak; overshoot less than 1%; and recovery time 50 μs .

Radiation meter. Gelman Instrument Company, 106 North Main Street, Chelsea, Michigan, U.S.A.

The meter operates in radiation fields from 5 mr to 300 r per hour and its effective energy range is from 0.075 to 2.00 Mev. Radiation intensity is measured on a scale of 4.25 in. length. The meter is transistorized and will operate for 50 hours on dry cells. It is portable, measuring 3 in. $\times$ 3 in. $\times$ 5 in. and weighs 25 oz. The instrument is fully stabilized and does not require re-calibration or adjustment.

Hewlett-Packard oscilloscope model 170A. Livingston Laboratories Ltd., Retcar Street, London N.19.

This is a general purpose oscilloscope of DC–30 Mc/s bandwidth, with plug in amplifiers on both X and Y axis.

There are 24 calibrated sweep rates from $0.1 \mu\text{s/cm}$ to 5 s/cm , accurate to 3%, which together with a seven-range magnifier provide maximum sweep speed of $0.02 \mu\text{s/cm}$. Also incorporated are an internal calibrator providing voltages from 0.2 mv to 100 v peak, an automatic beam finder and versatile triggering facilities.

Vertical amplifiers include the model 162A Dual Trace with a sensitivity of up to 20 mv/cm and a rise time of 14 ns. Horizontal units available include the 166C Display Scanner which enables permanent records of repetitive waveforms to be made on an X–Y plotter and the Model 166D Sweep Delay Generator for delaying the sweep from 2 μs to 10 s as well as allowing observations of low and high speed phenomena on the same trace. The instrument is built to U.S. military requirements with regard to shock, vibration, humidity and temperature effects.

New high definition photomultiplier for ultra-violet applications. Mullard Ltd., Mullard House, Torrington Place, London W.C.1.

The 56 UVP is a 14-stage high-definition photomultiplier tube, closely similar to the 56 AVP, but fitted with a quartz end-window and having a useful response down to 2300 Å. The specially designed input electron-optical system with a curved photocathode reduces the transit time difference between electrons arriving at the first dynode from the periphery of the photocathode and those arriving from the centre to 0.3 ns. Uniformity of transit times through the multiplying stages is maintained by careful shaping of the dynodes and by additional focusing electrodes between each stage which progressively narrow the electron beam. As a result the output pulse at 2 kv total supply voltage has a rise time of 2 ns, and a width at half height also of 2 ns.

The photocathode has minimum useful diameter of 42 mm, the average sensitivity is $50 \mu\text{A/lm}$, and the peak spectral response is at 4000 Å. At 2 kv total supply voltage the minimum gain is 10^8 , and the corresponding dark current is less than $5 \mu\text{A}$. The maximum peak anode current is 1 A. The tube, which has a 20 pin (bidecal) base, has a maximum overall height of 190 mm, a maximum seated height of 175 mm, and a maximum diameter of 55 mm.

Gamma radiation monitors. Associated Electrical Industries Ltd., Harlow, Essex.

Designed for high accuracy area monitoring of gamma radiation, both linear and logarithmic instruments have been introduced by A.E.I. Instrumentation Division.

To obtain optimum flatness of gamma energy response both types employ a large and sensitive ionization chamber.

d with argon and air. An unusual feature, incorporated in both instruments, is the use of an electrometer valve as a mode follower. Other features are transistorized circuits (including the input electrometer stage) and an instrument interlock system. The latter overrides the alarm trip and can be used to energize a visual or audible warning differing in character from the radiation alarm, thus eliminating the main cause of false radiation alarms. Failure to safety is ensured, relays being de-energized in the alarm condition.

The instruments are contained in splash-proof cast-minium desiccated cases, and the ionization chamber may be mounted remotely or on top of the case. Provision is made for remote recorder or meter facilities. To prevent accidental or inadvertent alteration, all the setting controls and the main fuse can be reached only by withdrawing the chassis from the case.

The linear instrument (type G.M.1) has four measuring ranges, 0–125 mr/hour, 0–250 mr/hour, 0–500 mr/hour, 0–1000 mr/hour, with a relative accuracy to $\pm 3\%$ f.s.d. and stability, over 7 days, of better than 2%.

The type G.M.2 instrument has a measuring range extending from 0.1 mr/hour to 10 mr/hour calibrated logarithmically over 5 decades. It has a zero indication, a relative accuracy to $\pm 3\%$ f.s.d., and a stability to $\pm 2\%$ over 7 days.

McLeod gauge. N.G.N. Electrical Ltd., Accrington, Lancs.

The N.G.N. McLeod gauge is operated by a new method which eliminates the need for a secondary vacuum pump and results in a unit which is only 15 in. high, suitable for bench mounting or building into equipment.

A vacuum balanced piston is used to displace the mercury to the glass gauge head. The balancing vacuum on the other side of the piston is maintained via a second leg of the gauge head connected to a point above the highest level the mercury can reach. Operation of the gauge is by a handle which is turned through 90° to raise the mercury to the level necessary for measurement. On release of the handle the mercury automatically returns to the lower position ready for the next measurement.

The glass gauge head is completely enclosed in a metal shield with Perspex front. Adjustment of the scale position is accomplished from outside this shield. Connection to the vacuum system is via a B 14 male cone joint, and no special precautions are necessary when evacuating the gauge prior to measurement. Two readily interchangeable gauge heads are available, covering the ranges 10^{-4} mm to 1 mm Hg, and 10^{-3} to 10 mm Hg.

Audio-frequency spectrum analyser. Federal Scientific Corporation, 615 West 131st Street, New York 27, N.Y., U.S.A.

The Model 4A Simoramic Spectrum Analyser performs Fourier analyses at the rate of one complete analysis every second over a frequency range of 200 c/s which may be positioned anywhere in the audio-frequency range. It is timed so that the analyser operates about 200 times faster than a conventional swept-frequency analyser of comparable selectivity, and that it is superior to instruments using parallel resonant circuits for the observation of spectra changing with time.

The instrument is based on the use of a delay line in a feedback loop whose gain and phase are closely controlled. The phase of signals in the loop is adjusted continuously at a rate coherently related to the total loop delay. This causes

reinforcement of signals in successive circulations in a manner which leads to a final output presented as a deflection-modulated oscilloscope display, showing the amplitude of the Fourier components on a time base bearing a linear frequency calibration. As soon as the display is presented the delay line loop opens briefly to discharge its contents, after which a fresh processing cycle begins immediately. A pilot pulse continuously circulated with the signal furnishes a positive indication that the entire instrument is functioning properly.

The instrument has three input voltage ranges, full scale inputs being 1 v, 10 v, and 100 v r.m.s. The selectivity, which is independent of frequency, is 1.3 c/s 3 db bandwidth, and 12 c/s 40 db bandwidth. The frequency accuracy is ± 1 c/s, and the level of all distortion products and hum is at least 40 db below full scale. An electrical output is provided, suitable for auxiliary display or recording, and digital read-out accessories are also available.

Annotated metallographic specimens. Metallurgical Services, Reliant Works, Betchworth, Surrey.

A collection of 139 annotated metallographic specimens is available presenting the basic features of metallographic structures and covering a wide range of industrial materials, both ferrous and non-ferrous, in cast, wrought, and heat-treated conditions. In order that the notes which accompany the specimens may be conveniently arranged, the specimens are arranged in small balanced sets, each consisting of the same class of material, but separate specimens are also available.

The specimens are numbered for identification, and their surfaces are such that they may be taken directly on to grinding papers. The material is generally in the form of round bars, usually $\frac{3}{8}$ in., $\frac{1}{2}$ in. or 1 in. in diameter. For cast materials, transverse specimens $\frac{3}{8}$ in. thick are supplied, but with wrought materials the specimens are taken longitudinally and are $\frac{3}{8}$ in. long. If required, extra specimens showing the transverse structure of wrought materials can be supplied. The notes give a brief survey of suitable methods of preparing the specimens, followed by a full description of the structures to be found in them. The metallurgical condition of each specimen is clearly specified, and the composition is given either as a close nominal figure, or more usually in the form of an analysis.

Vertical laboratory mixer. Atlantic Research Corporation, Alexandria, Virginia, U.S.A.

The model 60 LP vertical laboratory mixer, which is suitable for mixing high-viscosity fluids and castable polymers, has a mixing chamber capacity of 60 in³ but can be used to mix batches as small as one tenth of this. Two synchronized intermeshing blades and close chamber tolerances ensure intimate mixing. The mixing chamber is complete with vacuum connections, and is surrounded by a jacket fitted with a thermocouple so that mixing can be carried out at controlled temperatures. The mixer is also suitable for remote operation by 'mechanical hands'.

The bearings are located outside the mixing chamber, so that there is no possibility of bearing contamination. All parts in contact with the mix are of stainless steel, and the whole mixer may be dismantled for easy cleaning. A Perspex lid allows observation of the mixing action and rests on a large O-ring, which seals the chamber under vacuum. Mixing speeds may be varied from 50 to 250 rev/min.

Notes and comments

Notes on the Preparation of Papers for the *Journal of Scientific Instruments*

The following instructions refer to the main points which have to be considered in the preparation of a paper for publication, and authors offering papers to the *Journal of Scientific Instruments* for publication are asked to conform to these recommendations.

Manuscripts

Manuscripts should be typed in *double* spacing on paper not wider than 8 in. and not longer than 13 in. Only one side of the paper should be used, and a margin of 1–1½ in. should be left. As alterations in the text cannot be allowed once the paper is set up in type, authors should aim at absolute clarity of meaning and of typing, and should check the typescript carefully before submission. All manuscripts should be submitted in duplicate, and in addition to the fair copies, a set of small copies or prints of the diagrams (not larger than foolscap) must be attached to each MS. (This enables MSS. to be sent to two referees at the same time and so assists rapid publication.)

Abstract. An abstract is printed at the beginning of the paper immediately after the title, name(s) of author(s), and place of employment of author(s). Two extra copies of the 'title and abstract' page are required for the records.

Mathematics. It is not necessary to give detailed derivations of mathematical expressions and formulae in a published paper when the work is straightforward; it is quite sufficient to indicate the method of treatment and the final results.

References. In the text bibliographical references are made by giving the name of the author and the year of publication in brackets, e.g. (Jones 1942), and details are given in the last section, 'References', where the references are arranged in alphabetical order of authors' names and in date order for each author.

Drawings

Drawings should be in Indian ink on tracing cloth, tracing paper or white card, with lettering in soft or blue pencil; lettering of a size suitable for reduction will be inserted by our draughtsman. The drawings should in general be sufficiently large to allow of reduction in printing, and the lines should therefore be bold; the frame lines of graphs should be slightly finer than those of the plotted curves.

Full details are available in the Institute and Society's 'Notes for Authors', obtainable from the Editor and Deputy Secretary, The Institute of Physics and The Physical Society, 1 Lowther Gardens, Prince Consort Road, London S.W.7.

Papers for publication in the *Journal of Scientific Instruments* should be sent to the Editor and Deputy Secretary at the same address.

Publication of Conference Reports

It is hoped in future to publish short reports of any Conferences which are likely to be of interest to readers of the journal.

The Editor would be very grateful if any members of the Institute and Society who will be attending a Conference would let her know if they would be willing to write a report on it. This should be up to 1000 words in length and should be a general survey of the Conference mentioning any particular points of interest.

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British Journal of Applied Physics

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NOTES AND NEWS

Notes and comments.

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Device designed to maintain a constant gas pressure in kinetic systems

E. R. S. WINTER, D.Sc., F.R.I.C., D.I.C., John & E. Sturge Ltd., Wheellys Road, Birmingham, 15

Received 10th May 1961

Abstract

A vacuum-tight stainless steel piston pump containing mercury is described which can be attached to a glass high-vacuum line. The movement of the piston is controlled to raise or lower the level of mercury in a glass burette as to keep the pressure in the system constant. The movement of the piston is recorded upon a chart driven by a synchronous motor to give a record of the volume change with time in the gas phase at constant pressure; the chart speeds are provided. Pressure control is by attached Pirani gauges in a Wheatstone bridge network for low pressures, or by a mercury manometer with sealed-metal contacts at higher pressures; associated circuits are described.

1. Introduction

There are many cases in the studying of gas/solid reactions when it would be very convenient if the rate of evolution or disappearance of a gas in a closed high-vacuum system could be studied accurately and in detail at constant pressure. Thus, over the past few years, there have

been several important investigations of the rate of uptake of gases by metal films which suffered from the lack of suitable equipment for this purpose (Lanyon and Trapnell 1955, Eley and Wilkinson 1960, and Roberts 1961). Taylor and Strother (1956) described an apparatus in which mercury was driven up a burette to keep the pressure constant during adsorption of gases upon finely divided solids; the motive force was provided by the gases formed on electrolysis of water in a reservoir attached to the burette, the electrolysis current being switched on and off by means of contacts sealed into a mercury manometer connected to the gas system. This principle is useful when operating at pressures of about 1 cm and upwards but in practice, when used to follow rapid processes, it suffers from a variable time lag due apparently to sluggishness in the electrolytic cell; this is probably a temperature effect as it depends upon the frequency of switching on and off. In addition, there is a tendency to overshoot due to the evolution of gas from the cell for a short time after the electrolysis current is switched off. Neither of these defects is important when following slow processes over many hours. Workers at much lower

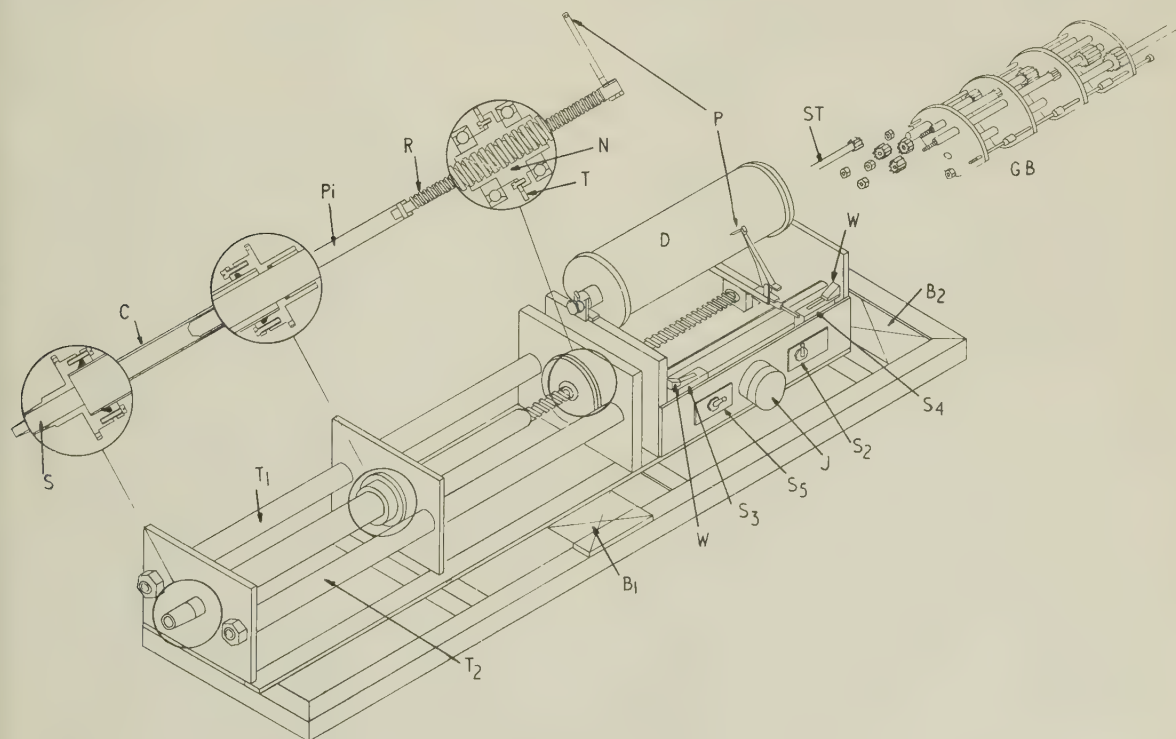


Fig. 1. The mercury pump.

pressures ($\sim 10^{-1}$ mm and lower) have either avoided the problem or have resorted to manual adjustment of burette mercury levels, using a direct-reading instrument, such as a Pirani gauge, as a pressure monitor (Roberts and Tompkins 1959); this is tedious and requires the constant attention of the operator.

2. Apparatus

The device described here is essentially a glass gas burette containing mercury connected to a stainless steel pump, the plunger of which is driven into the mercury by a small electric motor. The motor is switched on and off by the off-balance signal from a pair of matched Pirani gauges when working at low pressures, or by two contacts sealed into a mercury manometer at higher pressures. The pump is so designed that the full stroke delivers exactly 100 ml. and the movement of the plunger is automatically recorded upon a drum driven by a synchronous motor, thus giving an accurate record of the change of volume with time. Various refinements are included; for instance, the apparatus may be switched to work in reverse, i.e. to record the evolution of gas at constant pressure; the drum drive has three speeds of rotation, thus enabling processes of widely differing rates to be recorded, and a rapidly acting electromagnetic brake is included in the drive mechanism to avoid overrun.

The apparatus may conveniently be described in three parts: (a) the pump and recorder gear and allied circuits; (b) the circuit associated with the Pirani gauge; (c) a method of working at higher pressures.

(a) *The pump.* A semi-exploded view of the pump is shown with the driving motors removed in Fig. 1. The apparatus is substantially built, mainly of stainless steel, and mounted upon a welded 1 in. $\times$ 1 in. $\times$ $\frac{1}{8}$ in. angle-iron base. The driving motor, mounted upon base-plate B_1 and controlled by the Pirani gauge circuit or similar device, is connected by a chain drive to the chain-wheel T, which is rigidly attached to the phosphor-bronze nut N held between fixed guides (angular contact bearings) on the 14 in. long, $\frac{3}{4}$ in. diameter mild steel rod R, which has a two-start $\frac{1}{4}$ in. lead square thread. The use of this type of threaded rod and nut prevents all backlash or looseness in the drive. The rod R is bolted into the end of the piston Pi and rotation of T moves Pi in or out of the cylinder C, which is filled with mercury and connected by a standard B.19 stainless steel tapered cone S to the burette and the glass vacuum system. A pen P is attached to the end of R and records the extent of movement of the piston directly upon the drum D, which in turn is rotated at known rates by the gear-box, GB, driven by a synchronous motor (not shown in Fig. 1) mounted upon the base-plate B_2 . D is a light brass drum, 30 cm circumference by 25 cm long, and is conveniently loaded with a piece of millimetre graph paper for each experiment. D is mounted upon a steel shaft ST, 0.25 in. diameter, resting at each end in slotted steel angle plates and connected to the gear-box drive. A friction clutch allows rotation to the zero position of the time chart at the commencement of a run. The pen P is held in light contact with the chart by a small spring attached to the base of the arm holding P; both ends of the pen-mounting are extended over guides made by flattening the top surfaces of the two tie-bolts T_1 and T_2 , and the front extension operates limit switches at each end of its traverse. The limit switches S_3 and S_4 (see also Fig. 2) are Bulgin type S.511 microswitches fitted with small Tufnol wedges W (see Fig. 1), to ensure positive engagement with the end of the pen mounting.

The main driving motor and magnetic brake connect are shown in Fig. 2: the motor is mounted on the base-plate B_1 as indicated in Fig. 1 and the Londex relay RL2 and magnetic brake are fixed just behind this, below the front tie-bolt.

Other essential details are: the main drive motor is Parvalux type SD7 with double reduction gear and speed wound variable speed; it has a maximum torque of 15 lb ft and a range of 0.75 to 60 rev/min. The field and armature leads are brought outside the casing for reversing. The motor shaft is extended at the commutator end for the mounting of the Marvin and Wright magnetic brake. The drive is taken from the motor low-speed shaft by an 8 mm chain drive, a 12-tooth chain wheel driving the 30-tooth chain wheel T (Fig. 1) mounted on the phosphor-bronze nut N. The full stroke of the piston takes 120 seconds with the

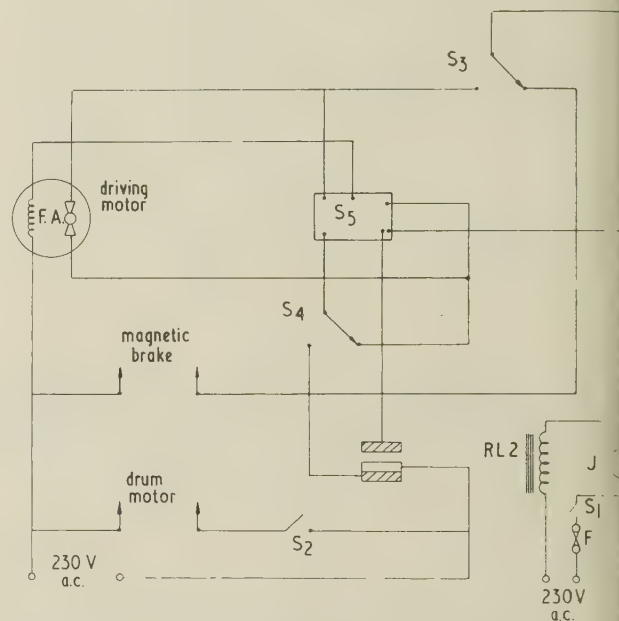


Fig. 2. Motor control circuit.

S_1 , S_2 , single-pole, single-throw toggle switch; S_3 , S_4 , Bulgin S.511 microswitch; S_5 , double-pole, double-throw toggle switch; RL2, Londex relay type LF; J, junction box; F, 5 A fuse.

drive. The chart drum motor is a Parvalux type SD7 1/150 h.p. synchronous motor fitted with worm reduction gear to give 1 revolution in 20 minutes; a change-speed gear-box is fitted between the drum and the drive and shown in an exploded form in Fig. 1; this enables a choice of three drum revolution times—20, 60 and 180 minutes. Using the slowest speed, processes taking 48 hours or longer can be clearly recorded upon one chart with no ambiguity.

Details of the construction of the pump and of the method of ensuring gas- and mercury-tight seals at each end of the barrel are shown in Fig. 1. The ram seals at each end of the cylinder are made by Edwards type VOR 138 O-rings and that through which the piston travels uses a type VOR 138 O-ring. The pump is designed to be fixed firmly to the laboratory work bench and to run in a horizontal position to minimize the risk of leaks (none have been encountered); it is arranged that the working level of the mercury in the burette, which is attached to the pump, is at least 80 cm above the piston.

The motor control circuit is shown in Fig. 2 and calls for no special comment; the brake is a Marvin and Wright

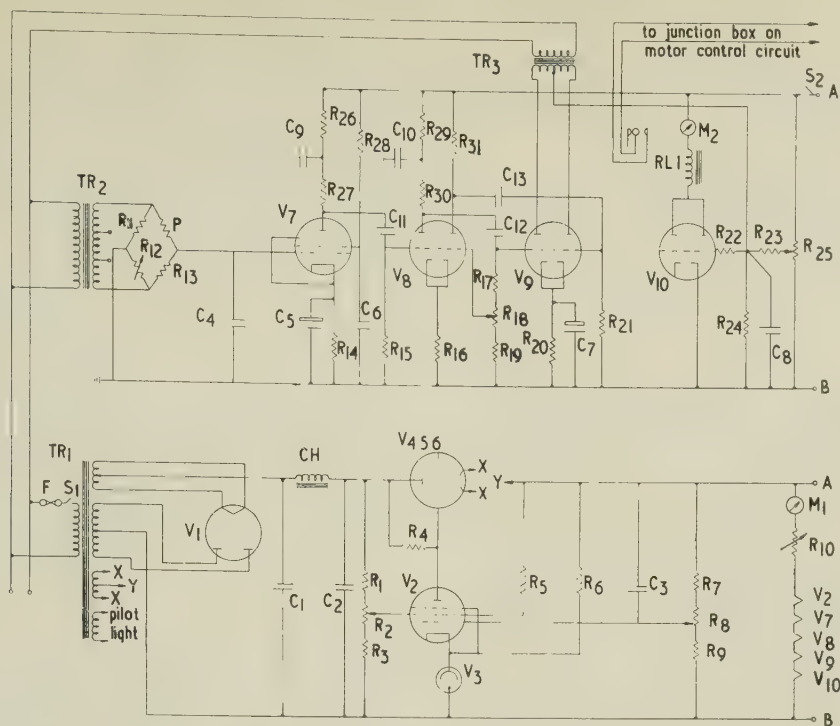


Fig. 3. Pirani gauge control circuit.

$C_2 = 8 \mu\text{F}$, 600 v
 $= 0.05 \mu\text{F}$, 500 v
 $= 100 \text{ pF}$
 $C_7 = 50 \mu\text{F}$, 50 v
 $C_8, C_9, C_{10} = 8 \mu\text{F}$, 500 v
 $= 0.1 \mu\text{F}$, 500 v
 $C_{13} = 0.25 \mu\text{F}$, 500 v
 $= 40 \text{ k}\Omega$, 10 w
 $= 25 \text{ k}\Omega$, 10 w, potentiometer
 $= 30 \text{ k}\Omega$, 10 w
 $= 0.1 \text{ M}\Omega$, 1 w
 $= 30 \text{ k}\Omega$, 10 w
 $= 15 \text{ k}\Omega$, 20 w
 $= 0.15 \text{ M}\Omega$, 10 w
 $= 10 \text{ k}\Omega$, 10 w, potentiometer
 $= 0.1 \text{ M}\Omega$, 10 w
 $= 1500 \Omega$, 100 w, adjustable

P = Pirani gauge

$R_{11} = 400 \Omega$ manganin
 $R_{12} = 0-1000 \Omega$ resistance box
 $R_{13} = \text{reference Pirani gauge}$
 $R_{14} = 1.7 \text{ k}\Omega$, 20 w
 $R_{15} = 470 \text{ k}\Omega$, 1 w
 $R_{16} = 1.5 \text{ k}\Omega$, 20 w
 $R_{17} = 47 \text{ k}\Omega$, 5 w
 $R_{18} = 20 \text{ k}\Omega$, 5 w potentiometer
 $R_{19} = 7.5 \text{ k}\Omega$, 5 w
 $R_{20} = 1.5 \text{ k}\Omega$, 20 w
 $R_{21} = 100 \text{ k}\Omega$, 1 w
 $R_{22}, R_{23}, R_{24} = 50 \text{ k}\Omega$, 10 w
 $R_{25} = 50 \text{ k}\Omega$, 10 w, potentiometer
 $R_{26}, R_{30}, R_{31} = 15 \text{ k}\Omega$, 20 w
 $R_{27} = 22 \text{ k}\Omega$, 20 w
 $R_{28} = 1.5 \text{ M}\Omega$, 1 w

$R_{29} = 3.3 \text{ k}\Omega$, 20 w
 (All resistances and potentiometers wire-wound)

$V_1 = 5\text{U}4\text{G}$
 $V_2 = 12\text{SH}7$
 $V_3 = \text{VR}105$
 $V_4, V_5, V_6 = 6\text{B}4\text{G's}$ in parallel
 $V_7 = 12\text{C}8$
 $V_8, V_9 = 13\text{D}1$
 $V_{10} = (\pm) 12\text{AT}7$

$\text{TR}_1 = \text{Special transformer (see text):}$
 primary 220-230-240 v 50 c/s;
 secondary 400-0-400 v at
 200 mA d.c.; secondary 5 v,
 3 A; secondary 6.3 v, 4 A c.t.;
 secondary 6.3 v, 2 A

$\text{TR}_2 = \text{transformer, } 220-230-240 \text{ v,}$
 50 c/s; secondary 18 v, 1 A
 $\text{TR}_3 = \text{transformer, } 220-230-240 \text{ v,}$
 50 c/s; secondary 250-0-250 v,
 100 mA

CH = 10 H choke

$\text{M}_1 = 0-200 \text{ mA}$, d.c. meter

$\text{M}_2 = 0-20 \text{ mA}$, d.c. meter

$\text{RL}_1 = \text{Post Office type } 3000 \text{ relay,}$
 5 k Ω coil

F = 5 A fuse

$\text{S}_1, \text{S}_2 = \text{single-pole, single-throw}$
 toggle switches

primar' electromagnetic brake unit, type Ints. No. 102.
 e leads from the junction box J go to the contacts on
 1 in the controller circuit, as shown in Fig. 3, or, when
 erating at higher pressures, to the corresponding contacts
 he high pressure control circuit (see paragraph (c) below).

b) *The Pirani gauge circuit.* The Pirani gauge circuit is
 own in Fig. 3. The off-balance signal from the Wheatstone
 dge network containing the Pirani and reference gauges
 applied to the grid of the first valve, amplified through
 V_7 and finally applied to the grid of one-half of V_{10} (the
 er half is not used) so as to energize the Post Office type
 y RL_1 ; this operates the relay RL_2 in the motor control
 uit, Fig. 2. It was found essential to provide the control
 uit with a highly stable power pack and to run the valve
 ters also off this supply: the circuit used is that developed
 he power pack for a d.c. amplifier for mass spectrometer
 (Graham, Harkness and Thode 1947).

he components are listed in the legend to Fig. 2: it
 uld be noted that TR_1 is specially wound so that the two
 ves of the h.t. secondary winding are exactly balanced
 there is an electrostatic shield between this winding and
 primary. The circuit of Fig. 3, run off the 230 v mains
 ough a constant-voltage transformer, has proved entirely
 able and stable in operation over continuous use for more

than two years. With the Pirani and reference gauges
 mounted side-by-side in a thermostat provided with good
 circulation from a vibration-free pump, the equipment
 records satisfactorily processes taking 48 hours or longer to
 complete, with no detectable zero shift. Using a Pirani
 gauge and reference each of resistance of about 300Ω , and
 a fixed resistance of 400Ω , a resistance box change of
 0.1Ω (~ 1 part in 4000) at the balance point, corresponding
 to an off-balance signal of approximately 2 mv from the
 Wheatstone bridge to the grid of V_7 , caused the main drive
 motor to stop or start.

(c) *Operation at higher pressures.* This is readily achieved
 by replacing the Pirani gauge by a mercury manometer with
 two sealed-in platinum or tungsten contacts at different
 levels and a provision for altering the mercury levels or
 otherwise adjusting the operating pressure. The two contacts
 may be connected to any simple switching device which
 works on an input of a few microamperes, and the output
 then fed to the junction box J of Fig. 2. A suitable circuit
 is that of Cram (1955) with the omission of the capacitor C_2
 in his diagram: this unit involves the interruption of a current
 of about $6 \mu\text{A}$ at a potential of 4 v, which causes negligible
 sparking at the contact in the gas phase in the control
 manometer.

Acknowledgments

Thanks are due to Dr. K. J. Hill, Mr. S. G. R. Hignell and Mr. L. A. Elliott for assistance with the design and for the construction of this equipment.

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Notes and Comments

Conference on Imperfections in Crystals

The X-ray Analysis Group of The Institute of Physics and The Physical Society will hold its Autumn Conference on Imperfections in Crystals on 17th–18th November 1961, at the Institution of Mechanical Engineers in London.

The three sessions of the Conference will be devoted to the nature of crystal imperfections and of associated diffraction effects, to experimental methods for studying imperfections, and to their influence on the physical properties of crystals. Included in the invited speakers will be Dr. P. B. Hirsch, of the University of Cambridge, and Professor F. C. Frank, of the University of Bristol.

Correspondence regarding the programme should be addressed to the Honorary Conference Secretary, Dr. G. S. Parry, Department of Chemical Engineering, Imperial College of Science and Technology, Prince Consort Road, London, S.W.7.

Enquiries regarding attendance should be addressed to the Administration Assistant, The Institute of Physics and The Physical Society, 47 Belgrave Square, London, S.W.1.

Instrument ball bearings

We have received from the British Scientific Instrument Research Association a copy of the booklet *Instrument ball bearings* by P. J. Geary. This is a survey of instrument ball bearings and constitutes the fourth section of the Survey of Instrument Parts being carried out by the British Scientific Instrument Research Association. The topics dealt with include types and grades of bearing, tolerances, truth of running, avoidance of vibration and noise, frictional torque, performance measurements, handling, mounting, lubrication, internal clearance, preloading and elimination of play, deflection under load and load capacity and life.

The price is 21s. Other publications in the same series are

Flexure devices (10s. 6d.), *Knife-edge bearings* (10s. 6d.) and *Torsion devices* (21s.). These booklets are all obtainable post free from the publishers, The British Scientific Instrument Research Association, South Hill, Chislehurst, Kent.

The Design and Production of Printed Circuits

We have received from Technograph Electronic Products Ltd. a copy of their brochure *The Design and Production of Printed Circuits*. Various types of printed circuits are described and there is also information on standard printed circuit tolerances, electro-plating specifications and the servicing of printed circuits. The brochure may be obtained from Technograph Electronic Products Ltd., Eros House, 29–31 Lower Regent Street, London, S.W.1.

British Standards Institution

We have received from the British Standards Institution notice of the following new standards: Telecommunication Components—B.S. 2133B, Part I, which lays down general requirements and tests for fixed ceramic dielectric capacitors, Grade II, and B.S. 2136, Part I, which lays down general requirements and tests for fixed metallized-paper dielectric capacitors for d.c. operation; B.S. 448, Electron valve bases, caps and holders (laying down dimensions for valveholders and for the gauges needed to ensure compatibility with the appropriate valves)—Section B8D/3 applies to valves having B8D type bases and Section 7/3 applies to valves having 5 or 7 lead-in-line bases; B.S. 1219M, a card setting out the recommendations and marks for the clarification of mathematical copy and the correction of mathematical proofs contained in B.S. 1219 : 1958.

Copies of these standards may be obtained from the British Standards Institution, Sales Branch, 2 Park Street, London, W.1.

Rotational vibroscope for the comparison of the torsional properties of thin fibres

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Abstract

The apparatus is described for the measurement of the dynamic torsional properties of textile fibres in the frequency range of 1 to 200 c/s using forced oscillations. The apparatus is particularly suitable for following the effects of the change in torsional properties caused by changes in temperature and/or humidity of the air surrounding the test specimen.

1. Introduction

IN the study of the mechanical properties of viscoelastic materials it is often desirable to measure their torsional behaviour at different frequencies. The methods that can be employed for these measurements are frequently limited by the physical dimensions of the specimen. The present paper is concerned with an apparatus developed specifically for the dynamic testing of thin textile fibres. The most commonly used method for the determination of the dynamic rigidity of textile fibres employs the freely oscillating torsional pendulum (see, for example, Meredith 1957). The period of oscillation and logarithmic decrement determine the torsional modulus and internal friction of the fibre suspension. However, this method is only suitable in the low frequency range of 0.2 to 0.02 c/s. A more refined measurement in which forced torsional oscillations are used in which operates at about 300 c/s has been described by Wakelin *et al.* (1955). The present apparatus also makes use of forced torsional oscillations and operates in the frequency range of 1 to 200 c/s. Since phase shift rather than amplitude resonance is used in the determination of the resonant frequency of oscillation, it is inherently capable of a much greater accuracy than the apparatus described by Wakelin *et al.* (1955).

2. Theory

The apparatus consists essentially of a supporting frame holding the fibre to be tested in a vertical position. At the approximate centre of the fibre a small magnet is cemented to the whole assembly placed in an oscillating magnetic field of variable frequency. The field exerts a couple on the magnet, causing it to rotate, the rotation being resisted by the torsional rigidity of the fibre.

If M is the moment of the magnet, H_0 the maximum field strength, ω the angular frequency of the field and θ the inclination of the magnet to the field at time t , then the applied couple is a function of position as well as time and is given by (Fig. 1)

$$L = MH_0 \sin \theta \sin \omega t. \quad (1)$$

If provision is made for the amplitude of oscillation to be kept small and θ close to 90° , then Eqn (1) approximates to

$$L \approx A \sin \omega t \quad (2)$$

where A is a constant. The fibre is thus set into forced torsional oscillation. The exact response of the system to the applied couple cannot be predicted unless the viscoelastic properties of the fibre are known. In general, however, it is found that at low amplitudes the resulting motion

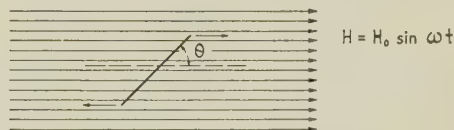


Fig. 1. Force acting on a magnet in a field which varies sinusoidally with time, when inclination between the magnet and field is θ .

is sinusoidal and lags in phase behind the applied couple. It is usual, therefore, to describe the moving system by the differential equation

$$I \frac{d^2 \alpha}{dt^2} + \eta \frac{d\alpha}{dt} + G\alpha = A \sin \omega t \quad (3)$$

where I is the rotational inertia of the magnet, η a viscosity or damping constant related to the internal friction of the fibre, G the rigidity or force constant relating angular stress to angular strain and α the angle of deflection of the pendulum. The constant η will include the effect of air damping on the motion, a factor which may be ignored at low frequencies but may become serious at high frequencies.

If condition (2) is not fulfilled, the motion of the system is not described by Eqn (3) but by a function of the Matthieu type, which shows stable and unstable solutions as well as a dependence of the resonant frequency on the amplitude of oscillation. Hence for the successful analysis of the problem, condition (2) is of great importance.

The solution of Eqn (3) is well known and leads to the result that amplitude resonance occurs when

$$\omega = \sqrt{\left(\frac{G}{I} - \frac{\eta^2}{2I^2}\right)}. \quad (4)$$

Phase resonance occurs (Burge 1961) when there is a phase shift of 90° between the applied couple and the resulting motion, under which condition

$$\omega = \sqrt{G/I}. \quad (5)$$

The rigidity of the fibre G is related to the torsional modulus of the fibre material through its dimensions, and is given by

$$G = 4I\omega^2 / \pi r^4 \left(\frac{1}{l_1} + \frac{1}{l_2} \right) \quad (6)$$

where r is the radius of the fibre and l_1 and l_2 the lengths of fibre from the magnet to the upper and lower supports, respectively. However, for many investigations the absolute value of the modulus need not be known and in such cases it is sufficient to determine G or even only the ratio of two rigidities under two specified conditions. Then from Eqn (5)

$$\frac{\omega_1^2}{\omega_2^2} = \frac{G_1}{G_2} \quad (7)$$

To determine the constant η in Eqn (3) it is most convenient to remove the applied oscillating torque on the fibre and allow the oscillation to decay, in which case the right-hand side of Eqn (3) becomes zero. It can be shown that the logarithm of successive swings is proportional to the damping constant and related by

$$\ln \left(\frac{\alpha_n}{\alpha_{n+1}} \right)_{\max} = \frac{\pi\eta}{I\omega} = \Delta \quad (8)$$

When the damping is small

$$(\Delta/\pi)G = \eta\omega \quad (9)$$

and the quantity $\eta\omega$ is known as the 'internal friction' of the fibre.

At high frequencies, when air damping may become appreciable, one may substitute a quartz (Lochner 1949) or tungsten suspension for the fibre and evaluate the damping due to air resistance separately, so that the results obtained with the fibre can be corrected.

3. Construction of the apparatus

A sketch of the apparatus is shown in Fig. 2 and is largely self-explanatory. The fibre a was cemented to the rod b ,

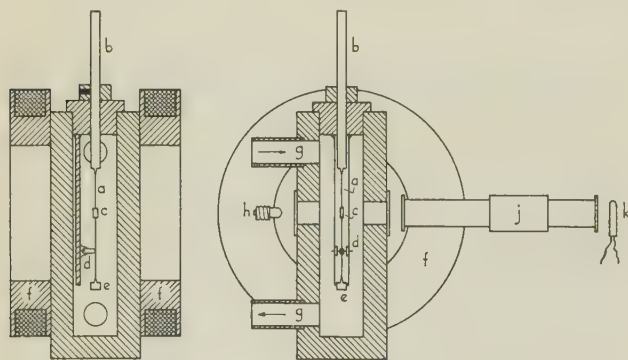


Fig. 2. Test cell showing fibre suspension, Helmholtz coils and optical system with phototransistor.

which could be rotated by hand or moved in a vertical direction. The tension of the fibre was held constant by the attachment of a small weight (0.5 to 1 g) e to the lower end, and the fibre was kept from rotating by cementing it to the point of the lever d , which was free to move in a vertical plane only.

The small magnet c fulfilled three functions. First, it provided the main rotational inertia of the moving system

and thus controlled the frequency range at which the fibre resonated. Secondly, it transmitted the driving torque to the fibre by its interaction with the magnetic field and, lastly, its shadow in a beam of light acted as an indication of the angular position of the fibre. The magnetic field was supplied by a pair of Helmholtz coils f , which were wound to match the 600 Ω output of an oscillator, carrying a maximum of 200 ampere-turns each at the full input of 40 v. However, it was only necessary to apply the full voltage of the oscillator when the magnets were very small, operating in the 200 c/s region.

The motion of the magnet was picked up photoelectrically. A 2 v prefocus torch light globe h provided a beam of light illuminating the magnet c . The shadow was enlarged by the reading microscope (4 cm focal distance) and cast on the phototransistor (type OCP 71) k . The output of the phototransistor was sufficiently large to be applied directly to the vertical amplifier of a cathode-ray oscilloscope (100 mv/cm).

For work at frequencies higher than 100 c/s, when the magnet became too small to cast a sufficiently large shadow, a piece of aluminium foil was added to increase its size without seriously increasing its inertia. Both hard and soft magnetic materials were used, the frequency of oscillation being twice that of the applied field for soft magnets. Helmholtz magnets were made by grinding pieces of high-speed hacksaw blade to size and magnetizing them in the required direction. A typical magnet weighed about 2 mg and measured 0.1 mm $\times$ 1 mm $\times$ 2 mm.

The supporting frame for the fibre, magnet and tensioning weight could be inserted into a chamber, making an airtight seal, and provisions were made to blow air, gas, at a controlled temperature and humidity through the chamber. Air speeds of 20 to 50 cm/s could be used before excess vibration affected the motion of the fibre.

The provision of air at a controlled relative humidity represented one of the experimental parameters of the investigation for which the instrument was built, namely the kinetics of the change of rigidity modulus with a change of relative humidity.

4. Operation

A comparison of Eqns (4) and (5) shows that for the determination of the rigidity constant G , it is advantageous to employ the 90° phase shift between applied couple and the motion of the fibre, rather than amplitude resonance. This was achieved employing the appropriate Lissajous figure on a cathode-ray screen, where the x-deflection signal was in-phase with the magnetic field driving the magnet. This signal was simply obtained from the voltage drop across a resistor R , connected in series with the Helmholtz coils. A simplified diagram of the arrangement is given in Fig. 2, together with the d.c. phototransistor balancing circuit, which was used to avoid all capacitive couplings, the amplification in the cathode-ray oscilloscope itself also being purely d.c.-coupled.

To fulfil the two conditions for the approximation (2) to be applicable, the maximum angular amplitude of the moving system at resonance was kept to less than 30° and the effective zero position of the fibre at 90° to the magnetic field. The latter condition was achieved by placing the light beam illuminating the magnet at 90° to the field and rotating the rod b in Fig. 2 until a folded Lissajous figure was obtained on the cathode-ray oscilloscope screen. Such a figure is produced when, in the course of one cycle,

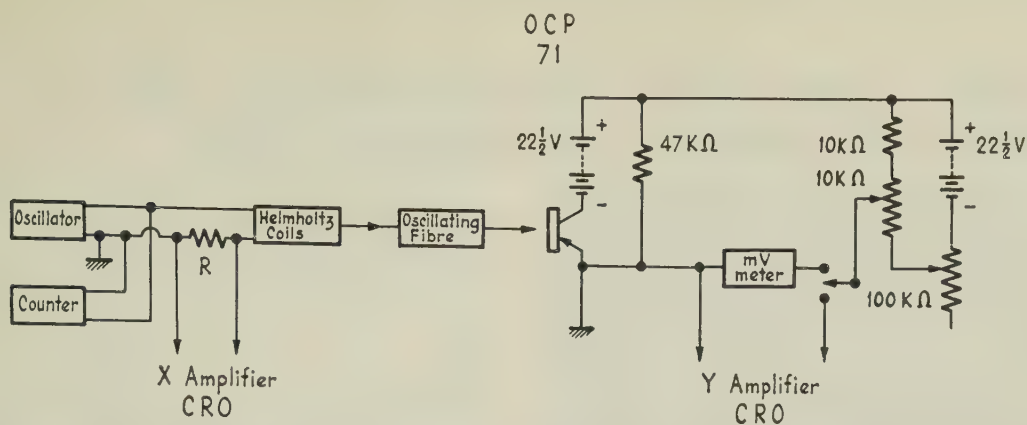


Fig. 3. Diagrammatic circuit arrangement for obtaining Lissajous figures on cathode-ray oscilloscope indicating resonance.

lation, the magnet deflects equal amounts on either side of an arbitrary zero position. By locating the light beam at angles to the field, this virtual zero position of the magnet could be located accurately. It corresponds to a position of the magnet in the light beam when the shadow is minimum. The appearance of the various Lissajous traces shown in Fig. 4.

elastic properties of textile fibres with changes in temperature and relative humidity. However, the instrument could also be used for the absolute determination of the viscoelastic constants, provided the characteristics of the rotating system were found by calibration against suspensions of known elastic constants or by calculation from the physical dimensions of the fibre and suspended magnet.

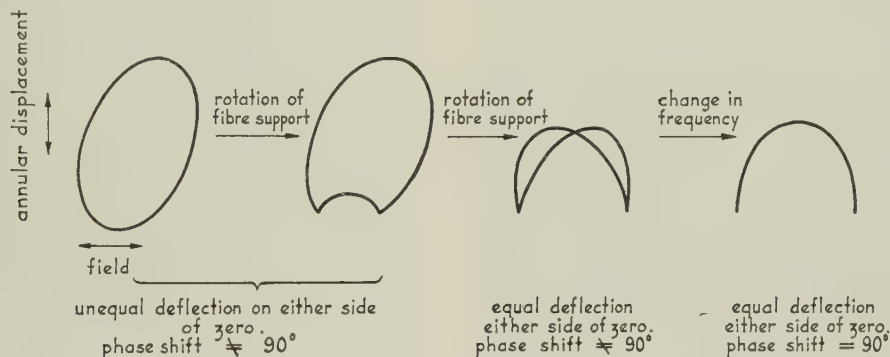


Fig. 4. Appearance of Lissajous figures indicating resonance and orientation of magnet in oscillating field.

the determination of η according to Eqn (8) was carried out using the free decay of the torsional pendulum by switching off the supply to the Helmholtz coils. This reduced the output to the x-amplifier to zero at the same time and produced a point oscillating in the y-direction on the cathode-ray oscilloscope screen. The amplitude of oscillation was proportional to the angular deflection of the fibre within an accuracy of 1%, provided the angular deflection was less than 10° on either side of the zero position. The trace of the oscillation was then photographed on a moving 35 mm film, from which the logarithmic decrement could be determined later.

5. Conclusion

The torsional vibroscope described here was designed primarily to follow the kinetics of changes in the visco-

In general, the frequency at which 90° phase difference existed between the applied couple and the resulting motion could be determined to an accuracy of 1 part in 1000, the accuracy dropping somewhat below 10 c/s. The evaluation of the damping constant, however, was only accurate to about 1 to 3 parts per 100.

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Production of light pulses of nanosecond rise time and duration by means of gas-discharge tubes

by Zs. NÁRAY and P. VARGA, Central Research Institute for Physics, Budapest, Hungary

MS. received 6th March 1961

Abstract

Short light pulses of rise time 3×10^{-9} s can be produced by a simple circuit arrangement containing commercially available gas-discharge tubes (e.g. thyratron tubes type 2050, voltage-stabilizer tubes type VR150). These pulses are of sufficient intensity to be displayed directly on cathode-ray tubes, using high-gain photomultipliers, without the help of amplifiers.

Introduction

SEVERAL methods have been developed for producing light pulses of short rise time. In the arrangement of Kerns, Kirnsten and Cox (1959), light pulses are produced by discharge caused by the interruption of a specially designed mercury relay. Whetstone (1959) uses an experimental arrangement containing a semiconductor constructed for this particular purpose. In Malmberg's (1957) arrangement light pulses of a rise time and duration of about 1 ns are produced by flash tubes designed specially for producing light pulses of fast rise.

In the following light-pulse generator, circuits for general laboratory application, operating with commercially available types of gas-discharge tubes (e.g. thyratron tubes types 2050 or 2D21 and voltage-stabilizer tubes type VR150) will be described. These circuits produce light pulses of rise times of a few nanoseconds.

The block diagram of the arrangement described here is shown in Fig. 1. The input trigger signal $T(t)$ fires the gas-discharge tube. The light emitted by the discharge produces

will be discussed. In order to obtain light pulses of fast time with these simple tubes, an auxiliary discharge is maintained in both circuits, which produces continuously carriers and ensures the quick development of the discharge after the trigger signal has been applied.

Light-pulse generator containing thyratron tubes

As is well known, by means of certain types of thyratron tubes, current pulses of nanosecond rise times can be produced. Particularly good results are achieved by using, for example, thyratron tubes types 2D21 or 2050. The circuit described in this section uses the light emitted by the thyratron tube in the conducting state for the production of light pulses. The advantage of the application of these types of thyratron tubes for producing light pulses lies not only in the fact that the light pulse has a short rise time, but also that owing to the gas filling of these tubes, the spectrum of the light emitted by the tube corresponds fairly well with the spectral sensitivity distribution of the multipliers generally used. From the point of view of some particular applications, however, the closed discharge volume of these tubes (particularly the type 2D21) which only allows production of pulses of relatively low light intensities, seems to be very disadvantageous. The tube type 2050, however, is suitable for the production (through the window on the mica sheet closing the discharge volume) of light pulses of sufficiently high intensity to generate signals of 100 v amplitude on the anode of a multiplier (gain of about 10^8).

Figure 2 shows a light-pulse generator circuit containing thyratron tube type 2050. The current in the thyratron starts with a delay of about 100 ns after the arrival of the input trigger signal $T(t)$. By controlling the bias voltage of the thyratron by means of the potentiometer P_1 , the shape

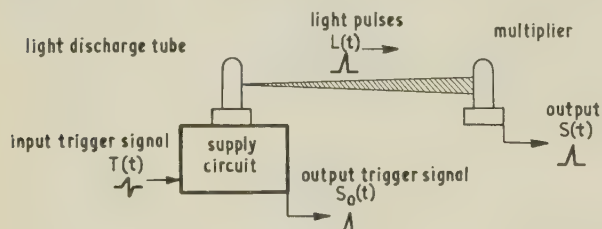


Fig. 1. Basic diagram of the light-pulse generator.

a light pulse $L(t)$ with a certain delay. Simultaneously a voltage pulse (the output trigger signal) $S_0(t)$, closely related as to shape and time of appearance with the light pulse, is produced by the circuit. As there is a certain delay between the appearance of $T(t)$ and the firing of the gas discharge which produces the light pulse $L(t)$, the input trigger pulse $T(t)$ may be used directly for the triggering of further circuits (e.g. the time-base of an oscilloscope).

Two circuits generating light pulses of nanosecond rise times by means of commercially available gas-discharge tubes

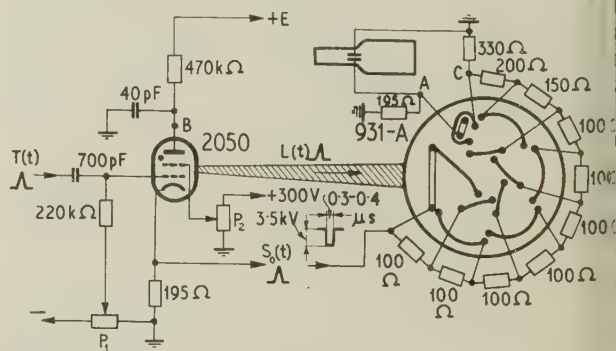


Fig. 2. Light-pulse generator, working with thyratron tube type 2050 and photomultiplier, for observing the shape of light pulse $L(t)$.

the ignition can be accurately timed. The device is operated at a repetition frequency of 1 kc/s.

At the very instant of the ignition the signal $S_0(t)$ is obtained from the cathode, and at the same time the light pulse $L(t)$ is produced by the thyatron tube in the direction of its longitudinal axis. The photomultiplier type 931-A used for investigating the light pulse is thus placed perpendicular to the longitudinal axis of the thyatron. To increase the gain, the photomultiplier is supplied by negative voltage pulses started simultaneously with the input trigger signal $T(t)$. These negative voltage pulses are of 3.5 kv amplitude and 0.3-μs duration. After the reduction of the dark current of the photomultiplier, as described by Naray (1955, 1956), its operation is improved to be trouble free.

The signal appearing on the anode of the multiplier is transmitted to one of the vertical deflection plates of a cathode-ray tube of high deflection sensitivity 7 v/cm.* The horizontal deflection of the cathode-ray tube is ensured by a sawtooth generator of a deflection speed of about 10^8 cm/s, triggered by the input trigger signal $T(t)$. The light pulse $L(t)$ and output trigger pulse $S_0(t)$ the oscillograms seen in Figs 3(a) and 3(b), respectively, are obtained. The length of the light pulse can be adjusted by a timing cable connected to the point B (see Fig. 2). The output pulse of the multiplier is shaped with the help of a timing cable of suitable length connected to the point A.

As can be seen in Fig. 3 the arrangement described above produces signals of satisfactory amplitude and of 3-4 ns rise time without any noticeable jitter. The jitter can be eliminated by an optimum adjustment of both the anode and second grid potentials in the thyatron tube (for the 2050 tube the optimum anode potential is 1400-1600 v). The voltage across the second grid is positive with respect to the cathode, there will be a gas-discharge current flowing continuously between the cathode and the second grid surrounding the whole electrode system; this means that near the cathode a permanent cloud of negative and positive charge carriers is formed, so that the current is started without delay by the input trigger signal in the direction of the cathode. The jitter is considerably less than 1 ns.

By altering both of the light-pulse generator and the sawtooth generator, can be completely eliminated by using the thyatron tube of the time-base generator also as a light-pulse generator. This procedure seems to be particularly convenient when measuring time fluctuations in the rise times of photomultipliers.

Light-pulse generator containing voltage stabilizer tubes

The voltage stabilizer tubes in general use have an open cathode volume, and thus the difficulties encountered in connection with thyatrons do not occur. These tubes, however, produce light pulses of slow rise time, of the order of microseconds, when supplying them by pulsed voltage (Naraykov 1956). The reason for this is that at the beginning of the discharge available charge carriers are not sufficient in number to accomplish a quick rise in the discharge, and thus the

When using cathode-ray tubes of low deflection sensitivity (type 5RP1A) the deflection can be increased by feeding into the deflection plates both the negative signal appearing on the cathode and the positive signal appearing on the last dynode (C in Fig. 2). Since the top of the high-voltage pulse supplying the multiplier is flat and the duration of the light pulse is longer than that of the light pulse to be measured, the positive signal occurring on the dynode in consequence of the light pulse will not be disturbed by the high-voltage supply pulse.

formation of the electron avalanche takes a relatively long time.

Considerable reduction in the rise time may be achieved by applying the circuit system shown in Fig. 4; here a small direct current is flowing through the voltage stabilizer tube

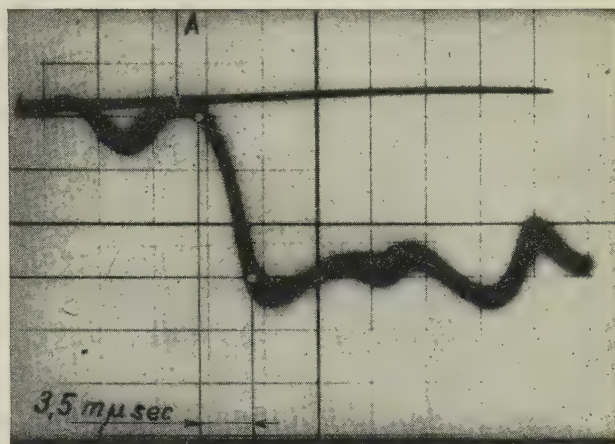


Fig. 3(a). Oscillogram of $L(t)$ taken with the arrangement given in Fig. 2. The multiplier anode pulse starts at A. The signal before A is a stray pulse arising from the current pulse $S_0(t)$.

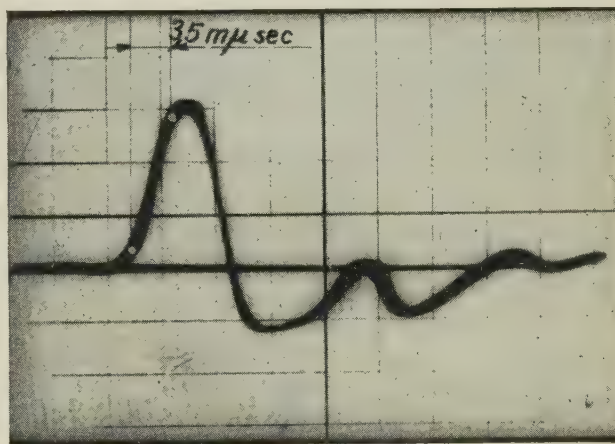


Fig. 3(b). Oscillogram of $S_0(t)$ taken with the arrangement given in Fig. 2.

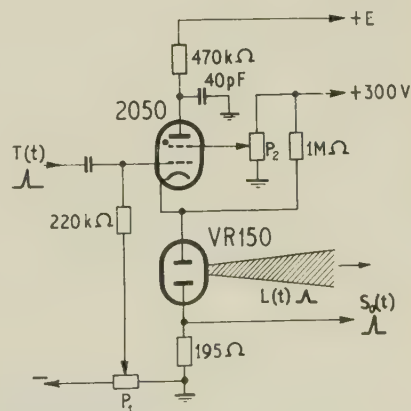


Fig. 4. Light-pulse generator working with voltage stabilizer tube type VR105.

type VR150, and thus the number of the charge carriers in the discharge volume is always sufficient. Upon ignition of the thyatron tube by the input trigger pulse $T(t)$ a voltage pulse appears on the terminals of the stabilizer tube. In consequence of this voltage pulse the light pulse $L(t)$ is emitted by the stabilizer tube and simultaneously the output trigger pulse $S(t)$ appears on the resistor inserted between the voltage stabilizer tube and the earth.

For measuring the light pulse emitted and the pulse $S_0(t)$, the arrangement shown in Fig. 2 can be applied. As to the jitter and the signal length, the explanations given in connection with Fig. 2 apply. The oscillogram obtained of the light pulse $L(t)$ generated with $E = 1900$ v, using the arrangement of Fig. 4, is given in Fig. 5. The rise time is 3 ns and the jitter is less than 2×10^{-10} s.

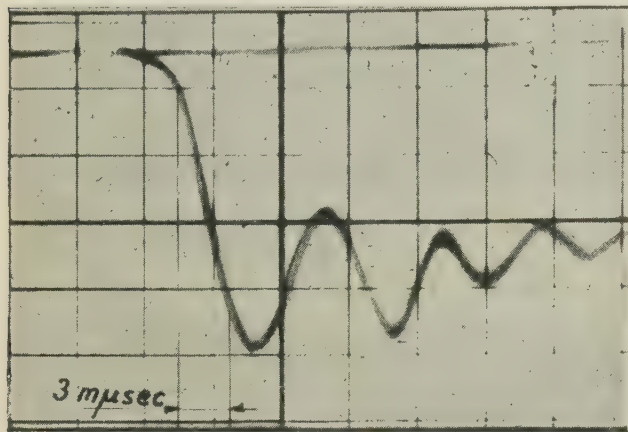


Fig. 5. Oscillogram of $L(t)$ taken with the arrangement given in Fig. 4.

Summary

It has been shown that light pulses of fast rise time can be produced by simple arrangements. The advantage of the circuits described above lies in the fact that the light pulse is actually delayed as compared to the input trigger signal $T(t)$, and thus the output signal of the multiplier can be displayed on a cathode-ray oscilloscope without any delay (that is, without the risk of distortion by delay cable) even if the time base starts a comparatively long time after the trigger pulse has appeared.

A disadvantage of the light-pulse generator should be mentioned: the wavelength of the light pulse cannot be chosen arbitrarily and the value of the intensity is also somewhat restricted when using one particular type of tube. This drawback, however, can be overcome by applying discharge tubes with gas-filling corresponding to the intensity and spectral distribution of the pulse to be produced.

Acknowledgments

The authors wish to express their most sincere thanks to Professor L. Jánossy for valuable discussions and to Titschka and E. Hamza for their co-operation in carrying out the experiments.

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Stabilization gauge power supply for use in a pulsed magnetic field

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Received 21st April 1961

Abstract

An audio-frequency power supply for the filament of an ionization gauge is described. The frequency chosen is higher than the natural frequency of oscillation of the filament, hence the gauge may be used in a magnetic field. Stabilization is achieved by comparing the potential at one end of a high-stability resistance through which the emission current is flowing with a reference potential, and controlling the filament current from the difference of the two. Stability over several weeks of continuous working and over a pressure range of 10^{-3} to 10^{-6} mm Hg is better than 1%.

Introduction

STABILIZED ionization gauge power supplies have been described previously. See for example Steckelmacher and Van der Meer (1950). Such supplies are not, however, suitable for gauges used in a magnetic field since the filament is heated by 50 c/s alternating current, which causes it to vibrate and eventually to break. A supply was required for an ionization gauge used with the Birmingham liquid hydrogen bubble chamber, which operates in a pulsed magnetic field. The pulse duration is two seconds and the repetition rate is ten seconds. The field strength at the chamber is 16 kG. This is produced by an air-cored electromagnet with a large leakage field at the position of the ionization gauge. The field gradient is also large and screening would be difficult. The time between pulses is sufficiently long to take vacuum readings, but not long enough to switch the gauge on and off and obtain an accurate reading.

Design considerations

There will in general be a force on the filament of an ionization gauge in a magnetic field due to the interaction of the heating current and the field. This force is zero only when the gauge is oriented so that current flows in the direction of the field. Stabilization of emission current is achieved by controlling the heating current from it. The direction of flow of emission current is perpendicular to that of the heater current, therefore the orientation for zero force on the filament is that for maximum force on the electrons flowing from filament to grid. During a magnetic field pulse the emission current would be considerably reduced and with a stabilized supply the filament current would increase in an attempt to counteract this reduction in emission current. If the filament were supplied with direct current it would suffer deflection at each magnetic field pulse. If, however, the current is supplied at a frequency much higher than the natural frequency of oscillation of the filament no vibration

will take place, and the orientation may then be chosen so that the magnetic field does not deflect the emission current. The stabilization therefore is not affected.

The gauges used were Edwards Type I.G. 2H(T) with uncoated tungsten filaments and plane parallel electrode geometry. The natural frequency of oscillation of a filament was determined by placing the gauge between the poles of a magnetron magnet and passing a current of about one amp at varying frequencies through the filament. The frequency at which maximum vibration of the filament occurred was about 700 c/s. The frequency chosen for the heater current, 5000 c/s, was determined by the optimum response of the audio-frequency transformer used.

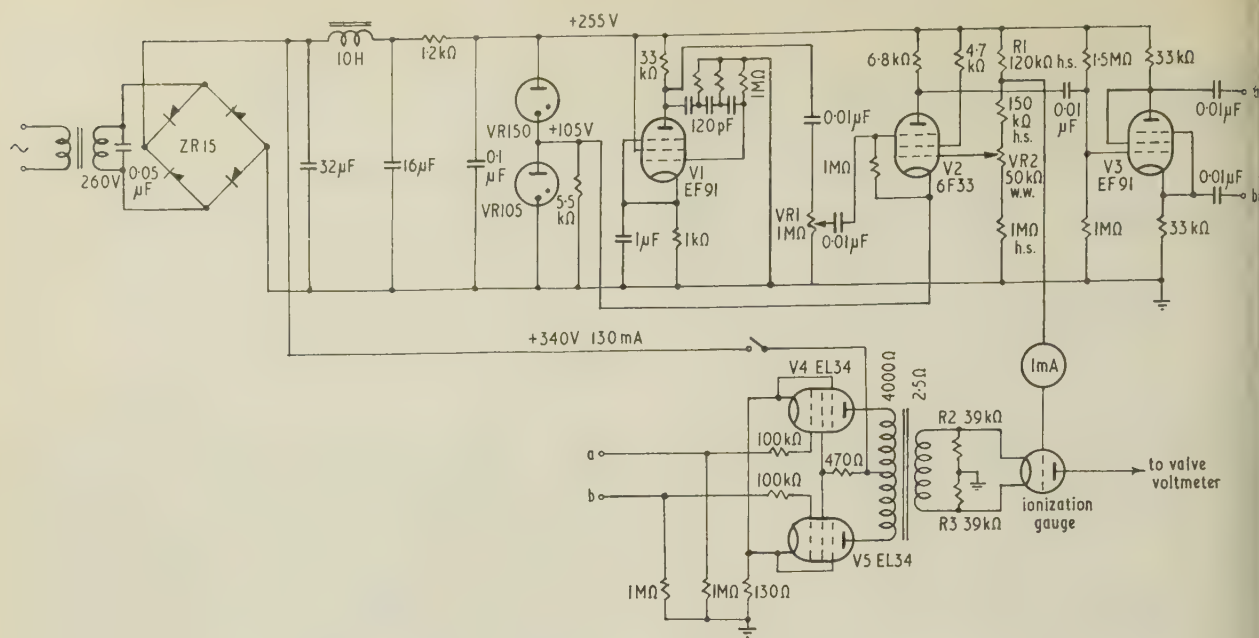
The circuit

The circuit diagram is shown in the Figure. The emission current of the gauge is passed to the modulator V2 which controls the amplitude of signal fed from the oscillator V1 to the phase splitter V3 and power amplifier V4 and V5. Valve V1 is a phase-shift oscillator. The audio-frequency voltage produced by this is fed to the suppressor grid of the modulator valve V2, the amplitude being adjusted by means of the potentiometer VR1 to give maximum modulation of the anode current without undue distortion. The cathode of V2 is at a fixed potential and the control grid voltage is determined by the emission current of the gauge which is fed through the 120 k Ω resistance R1. The value of R1 depends on the emission current required. In the present circuit the emission current is stabilized at 1 mA. Fine adjustment of the emission current is effected by means of the 50 k Ω potentiometer VR2. The output transformer is a 30 W Gardner Type OP 707. The filament of the gauge is maintained at a potential of 20 V positive with respect to earth by means of the two 39 k Ω resistors R2 and R3. The anode of the gauge is kept at earth potential by the valve voltmeter used to measure the positive ion current, and the grid potential is +120 V with respect to earth, +100 V with respect to filament.

The power supply provides 130 mA of current at 340 V for the power amplifier as well as 60 mA at a stabilized voltage of 255 V for the control circuit and valve voltmeter. The mains transformer is a Gardner type BS6060, secondary voltage 260 V, and the bridge rectifier is composed of Ferranti type ZR15 silicon diodes.

Performance of the circuit

The resistance of the filament of a gauge at operating temperature is approximately 2.5 Ω . The maximum current obtainable into a fixed resistance of this value is 3.4 A, compared with the maximum value of 2.9 A, required by



the manufacturers. The current into the same fixed resistance changes by 1 A for a change of 0.75 v in the modulator grid potential. This corresponds to a change in emission current of 0.7%. Lead resistance must be kept low compared with the gauge resistance otherwise the maximum current quoted will not be achieved. No precautions against oscillation needed to be taken. This is probably because the time constant of the filament is much longer than any in the modulator-amplifier system. Over a pressure range of 10^{-3} to 10^{-6} mm Hg and in continuous operation for several weeks the stabilization was better than 1%. Perfect alignment of the gauge in the magnetic field was not possible

and slight changes in filament current were observed during a magnetic field pulse. The positive ion current, however, varied markedly during a pulse and accurate measurements of pressure could only be made between pulses. For this reason it seems unlikely that the device could be used in a constant magnetic field, but in pulsed fields, for example, synchrotron magnets it would provide a useful method of obtaining vacuum readings.

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Smooth power control for high current furnaces

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received 30th March 1961

Abstract

A method is described whereby the temperature of resistance furnaces operating with currents of 500 to 2000 A can be adjusted continuously and smoothly. The furnace power is supplied from a saturable reactor, the output of which is controlled by a manually operated or motorized auto-transformer in series with a rectifier. The system described will provide power output voltage supplies which vary as the first, second or third power of the input voltage, in response to impulses from a thermocouple or total radiation pyrometer.

1. Introduction

FURNACES operating at temperatures within the range 2000–3000°C fall into two categories, viz. those with molybdenum, tantalum or tungsten elements in the form of a thin wire, strip or spiral of high resistance, which require relatively high voltages and low currents, usually supplied by auto-transformers, and those with carbide, oxide or graphite elements which require currents in the region of 500–2000 A at low voltages. The smoothness of power supply in a system of ganged auto-transformers, supplying a high current and low voltage, depends upon the mechanical sensitivity of the auto-transformer and on the spacing of the transformer windings. The ganging of transformers, where in some cases three, four or five are connected together, is a reliable method when temperature reproducibility and stability are required. Each auto-transformer has to be in series with the others to prevent overloading and the smoothing of power output and precise control of temperature is difficult because of the coarse transformer windings. A relatively powerful motor is required to turn the ganged auto-transformers and, if high gearing is used, the furnace temperature is usually found to vary sinusoidally with respect to time. One method of overcoming these difficulties is to employ a saturable reactor, which is a choke, initially in a state of magnetic unsaturation, that constitutes an impedance to the flow of current through the primary of the step-down transformer. When a d.c. voltage is applied to the coil, the impedance is reduced and this produces an increase in the current to the transformer. The transformer current, and therefore the furnace temperature, will depend on the value of the applied d.c. voltage.

2. Furnace power control

A saturable reactor has been used to control the power supply to a graphite tube resistance furnace of resistance approximately 0.02 ohm, operating at currents of up to 2000 A. For this particular furnace, at zero d.c. voltage applied to the saturable reactor the initial current in the secondary of the transformer is approximately 100 A giving

a furnace temperature of 50–100°C. For higher furnace temperatures the value of the d.c. current has to be increased. As the d.c. circuit is independent of the high current side of the transformer system, a low power auto-transformer may be used for voltage control and, having fine core windings, it will give a smooth relationship between output and angular rotation. The saturable reactor requires 40 V d.c. for full power output. This control voltage is supplied from a step-down transformer which reduces the mains voltage to 50 V a.c. The output of this transformer is fed to a 3 A auto-transformer (e.g. Variac) having a manually operated control. The output from this transformer is fed to a second 3 A auto-transformer which can be motorized or manually operated. The output from this transformer after full wave rectification, is fed to the d.c. coil of the saturable reactor. The control of a 20 kVA furnace can thus be carried out by a system operating at only 200 W, the automatic control system being driven by a 50 W motor.

The first auto-transformer is used to select a voltage slightly higher than that necessary to attain the maximum

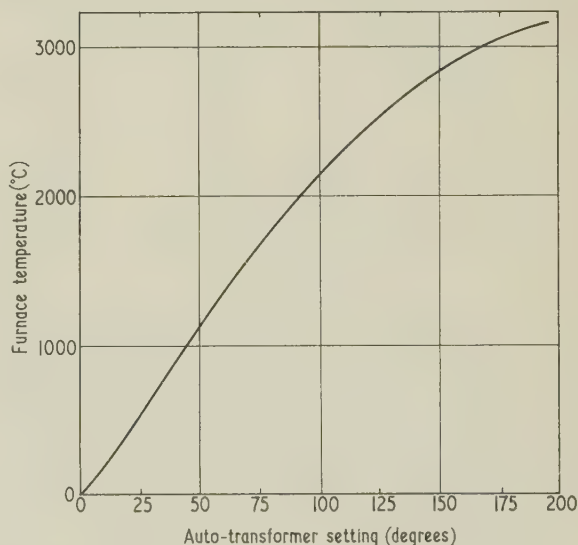


Fig. 1. Furnace temperature plotted against control transformer setting.

furnace temperature required. This enables the full 300°C rotation of the motorized auto-transformer to be used for control purposes ensuring maximum sensitivity of control (Fig. 1).

3. Programmed control of furnace temperatures

Any temperature control system to be used in conjunction with the power control system described in the previous

section should be capable of controlling the rate of heating to the soaking temperature, the soaking temperature and time at temperature and the rate of cooling.

3.1. Control of the heating cycle

As already described the power input to the furnace is controlled by the setting of the manually operated auto-transformer. The rate at which the temperature rises is therefore determined by the rate at which the reversible motor rotates the spindle of the auto-transformer. Alteration of the rate of rotation may be effected using a gear box which, for maximum flexibility of control, must be of infinitely variable ratio. A current regulator, in which the ratio of time ON to time OFF can be varied, will, if placed in the common line of the reversible motor circuit, act as a gearbox of variable ratio. Provided the time cycle of the regulator is less than about 25 seconds this approximates to a gearbox of infinitely variable ratio. For the graphite tube furnace referred to previously, average rates of increase of temperature as a function of auto-transformer setting and of the ON/OFF ratio are given in Fig. 2.

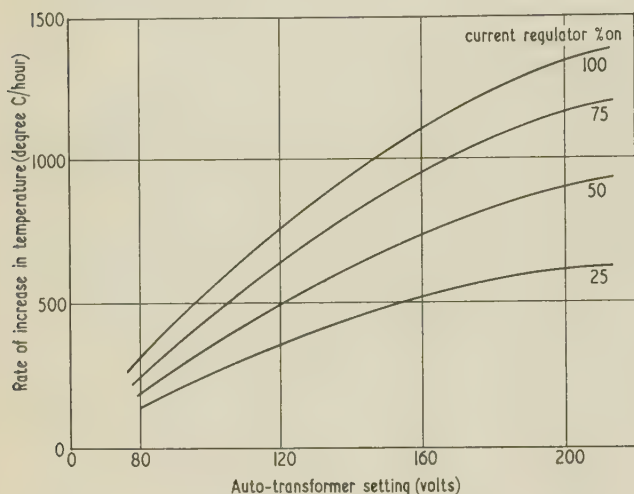


Fig. 2. Rate of temperature rise as a function of auto-transformer setting.

The power output given by this control system is a linear function of time. As the graphite tube furnace used in conjunction with this control system was of low thermal capacity and quick response over a wide range of temperature, heating rates were sensibly linear. However, it is conceivable that variable heating rates and non-linear power outputs may be required and the control system described is capable of modification to give a variety of heating rates as a function of time (Fig. 3).

If a second auto-transformer is mounted on the same motor spindle as the motorized auto-transformer from which it takes its input, then the output of this second transformer will vary as the square of the input voltage (Fig. 3, curve B).

If the number of auto-transformers ganged in this manner is increased to N , then $V_N = KV_1^N$ where V_1 = input voltage (which varies linearly with time), V_N = output voltage (with which temperature varies linearly), K = constant determined by the step down ratio voltage of transformer.

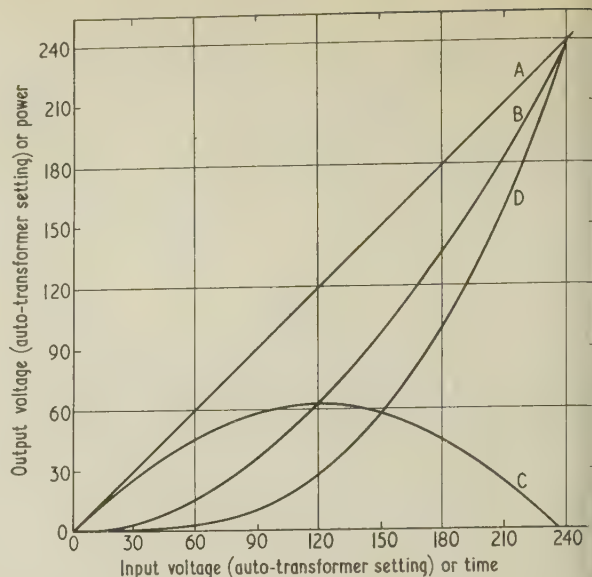


Fig. 3. Power output for linear, square, cube and cyclic control.

Curve	Auto-transformer				Power output:
	1	2			
A	motorized	fixed	$T = 0$	$V = 0$	linear
B	motorized	motorized	$T = 0$	$V = 0$	square
C	motorized	motorized	$T = 0$	$V = 240$	cyclic
D	motorized	motorized	$T = 0$	$V = 0$	cubic
	extra transformer				

$T =$ time, $V =$ auto-transformer (2) setting.

T = time, V = auto-transformer (2) setting.

3.2. Control of soaking temperature

The power having been switched on and the heating cycle selected, the furnace temperature, detected by a thermocouple or radiation pyrometer, will increase until the soaking temperature pre-set on a controller is reached. At the temperature the controller causes the motor to operate in reverse, off or forward direction depending on direction of the deviation from the set temperature.

Using a radiation pyrometer as the temperature sensing element and a controller, based on the operation of a microswitch by a cam mounted on the spindle of the potentiometer wire, temperature control was within ± 5 deg C at 2000° and ± 20 deg C at 2800° C.

3.3. Cooling cycle

At the end of the soaking period the timer is set to switch the motor to reverse, over-riding other signals from the controller. The rate of cooling will then be controlled by the same system as the heating cycle, with the variants already described.

When the auto-transformer has returned to zero output the furnace power is cut off by an arm, attached to the transformer spindle, which operates a microswitch.

Acknowledgments

The author wishes to thank Dr. L. E. Russell and Mr. Garrard for their suggestions and comments on the use of a saturable reactor, and Mr. R. J. Dugdale for carrying out the electrical installations.

Response of an X-ray opposite-window monitor system to changes in tube conditions

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Received 9th May 1961

Abstract

The variation of the intensity detected by an opposite-window monitoring system is investigated for large changes in the tube conditions. It is shown that if two normal filters are inserted in the diffractometer beam, this variation is 0.3%/kv when the tube current is kept constant. If any other number of filters is used the variation may be as large as 2%/kv and this variation is obtained. The variation with tube current, when the tube potential is kept constant, is shown to be 0.3%/mA.

THE use of a monitoring system with an x-ray diffractometer, to allow for any variations in the intensity of the incident beam, is a well-known technique and a number of such systems have been described (Hall *et al.* 1949, Greaves *et al.* 1952, Gillam and Heal 1952, Jones 1953, Pyle *et al.* 1953, Gillam and Cole 1953, Williamson and Hallman 1953, Kiss and Patla 1961). While the day-to-day reproducibilities of these systems have been investigated by various authors, particularly Gillam and Cole (1953), the present work of Kiss and Patla (1961) seems to be the first published account of the quantitative performance of a monitoring system subjected to large changes in the x-ray tube potential and current. The system described by them, though operating satisfactorily for changes in the tube current, is subject to considerable errors when the applied voltage is changed. This disadvantage is removed in the opposite-window monitoring system described below.

The apparatus with which this monitor is used (Pike and Hughes 1956, 1959) is fully automatic and is designed to be unattended for periods of hours. It has been found that with the self-rectified unstabilized power supplies used variations of up to 20% in voltage and current are possible, and the operation of the monitor system has therefore been investigated in detail for variations of this magnitude from normal operating conditions.

The monitoring system consists of a fixed-angle diffractometer set to detect the 111 line of a powdered aluminium specimen and is similar to the specimen diffractometer in that it has the same radius, take-off angle, Söller slit and divergence slit systems and detector. A receiving slit with an aperture of about $0.75^\circ(2\theta)$ is used to ensure that any small movement of the line position will not cause any change in the intensity at the monitor counter. The apparatus is designed to register the number of counts from the specimen while the monitor system registers 10000 or 1000 counts; the recorded count is automatically corrected for dead-time losses by the use of a Hughes-Eastabrook (1953) circuit. In order to obtain a suitable number of specimen counts the intensity at the monitor counter can be adjusted either by

inserting β -filters of the appropriate thickness in the diffracted beam or by changing the divergence slit.

The response of the monitor system was investigated by scanning over the 111 K_{α_1} line of an aluminium specimen in steps of $0.01^\circ(2\theta)$ with a fixed monitor count of 10000 at each setting. The background count, found at some convenient point, was subtracted from the number of counts at the peak to give the intensity of the line. The procedure was repeated three or four times for each set of experimental conditions, and the mean peak intensity of the line calculated. This was expressed in terms of the line intensity at some arbitrary experimental condition (35 kv, 12 mA) and the reciprocal taken. This quantity is a measure of the monitor intensity compared with the intensity of the K_{α_1} radiation diffracted by the normal specimen and will be referred to as the relative monitor intensity. Ideally this should have a constant value of unity for all experimental conditions.

The standard deviation σ of a count I thus recorded with a monitor count M is given (Peiser *et al.* 1955, p. 223) by $\sigma = (I + I^2/M)^{1/2}$, and hence the standard deviations of the relative monitor intensities obtained as above are estimated at 1%. All results were obtained using a Philips 25623/62 sealed-off copper-target tube with North American Philips Type 62019 Geiger counters as detectors, and are shown in Figs 1 and 2.

A nickel filter, approximately 0.03 mm thick, which reduces the intensity of the CuK_{α} beam by approximately 50% and almost completely absorbs the K_{β} radiation, was used in the diffracted beam from the specimen, and it might be expected, therefore, that the monitor system would operate most satisfactorily with a similar filter in its diffracted beam. The variation of the relative monitor intensity with applied voltage under these conditions is shown in Fig. 1, curve 1. The decrease in the relative monitor intensity with increase in potential is due to the use of the wide receiving slit, which is such that the intensity of the continuous radiation detected by the monitor system is an appreciable fraction (approximately 10%) of the whole. The total change in the counting rate of the monitor is due, therefore, to the change in intensity of the diffracted K_{α} radiation together with the change in the intensity of the continuous radiation detected. This latter increases less than does the K_{α} radiation for a given increase in potential, with the result that the relative monitor intensity decreases with increase in potential. The rate of change of the relative monitor intensity is approximately $-1\%/kv$, which is large enough to produce an appreciable error ($\sim 5\%$) in intensity measurements if the operating conditions are allowed to vary by the amount they can do if the instrument is left unattended for any length of time.

The largest number of foils which can be used in practice

to reduce the monitor intensity is 5 (a total thickness of approximately 0.15 mm), and the variation of relative monitor intensity with potential in this case is shown in Fig. 1, curve 2. The variation, which is of the order of $+2\%/kv$, can be readily explained. The thickness of the foil is now

the variations are kept to a minimum. If two foils are used in the present monitoring system, however, considerable errors can be caused by variations in the operating conditions. The monitor counting rate is adjusted, therefore, by altering the aperture of the divergence slit so that two foils are always present in the diffracted monitor beam.

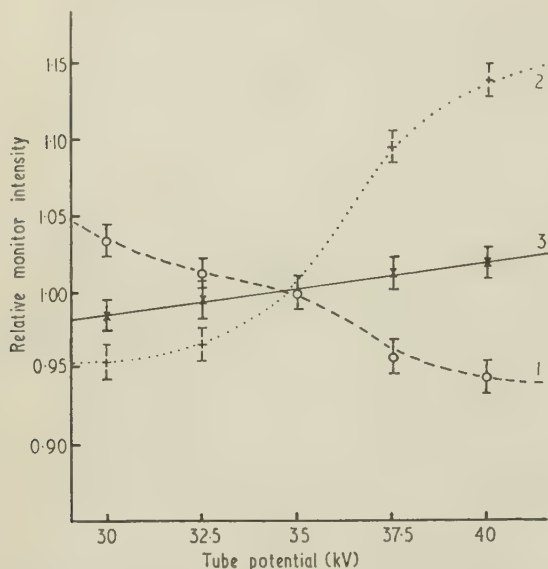


Fig. 1. The variation of the relative monitor intensity with tube potential. (Aluminium specimens; copper target; 12 mA.) Curve 1, 1 nickel foil in the diffracted beam of the monitor; curve 2, 5 similar nickel foils in the diffracted beam of the monitor; curve 3, 2 similar nickel foils in the diffracted beam of the monitor.

such that the greater part of the radiation detected by the monitor system is high-energy continuous radiation, and the variation in the observed monitor intensity is therefore largely dependent on the variation in the intensity of this part of the emitted spectrum. As the potential is increased the amount of continuous radiation with energy great enough to reach the monitor increases and hence the relative monitor intensity increases. This is complicated to some extent by the variation with wavelength of the quantum-counting efficiency of the Geiger counter used and the increased transparency of the filters to shorter wavelength radiation.

It can be seen from curves 1 and 2 that the effects mentioned are in opposition and that the relative monitor intensity can be made sensibly equal to unity over the whole range of conditions by suitable choice of filter thickness. This is very nearly achieved by the use of two foils, as shown in Fig. 1, curve 3.

The variation of the relative monitor intensity with tube current with two nickel foils in the diffracted beam is shown in Fig. 2; the magnitude of the variation is quite small, of the order of $-0.3\%/mA$. Kiss and Patla give no quantitative results, so that no comparison with their measurements can be made. The change in the relative monitor intensity is perhaps due to changes in focusing conditions (Peiser *et al.* 1955, p. 209).

The use of two foils in the diffracted beam of the monitor improves the performance of the monitoring system so that any change in the relative monitor intensity caused by variations in the potential or the tube current are not significant for the present work of the instrument on the A.S.T.M. Powder Data File, or indeed for most work, provided that

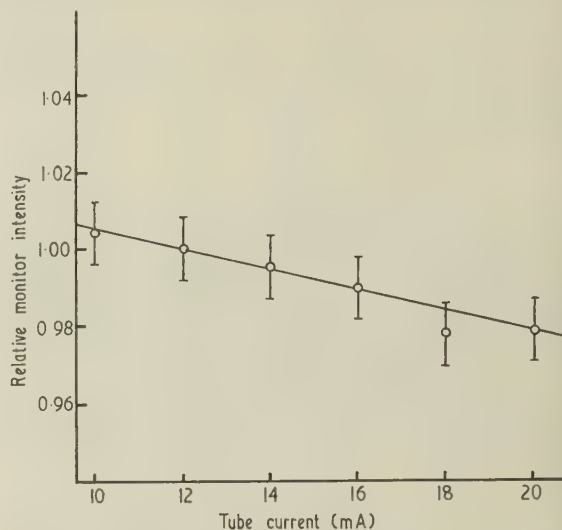


Fig. 2. The variation of the relative monitor intensity with tube current. (Aluminium specimens; copper target; 2 nickel foils in the diffracted beam of the monitor; 35 kv.)

Provided these precautions are taken the monitor system operates satisfactorily over a fairly wide range of tube conditions. For work of extreme accuracy it is probable, Kiss and Patla (1961) have suggested, that a combination of a monitoring system and stabilizing equipment is essential.

Acknowledgments

The author is indebted to Professor A. J. C. Wilson and Dr. J. W. Hughes for their interest and encouragement. The work has been carried out in connection with the author's employment by The Institute of Physics on work on the A.S.T.M. X-ray Powder Data File.

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Emission control for the omegatron-type mass spectrometer

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Received 23rd March 1961

Abstract

The basic circuit usually used with the omegatron provides a method of regulating filament emission to maintain a constant target or beam current. In operation, the basic circuit permits emission current variations of as much as $\pm 10\%$, together with long term electrometer zero drift of $\pm 5\%$, at an input impedance of 10^{10} ohms. A circuit of a new type used for emission regulation of ion gauges is modified to provide closed loop feedback control of omegatron filament emission. Use of this circuit, which monitors and controls the target current, results in emission control of $\pm 3\%$ and reduces long term electrometer zero drift to $\pm 5\%$.

A PROJECT has been initiated to determine the rate of change of the hydrocarbon content of an oil-diffusion pumped high-vacuum system as a function of fluctuations of the cooling water and cold-trap temperatures the input power to pump. To facilitate this investigation, an omegatron-type mass spectrometer was selected. In an investigation of this type (where the changes in the spectrum to be studied may be expected to occur only after periods of many hours or even days), a major problem connected with the use of the omegatron is the zero drift of collector current. This zero drift is the result of several

factors, the most important of which is the variation of ionization beam current. The basic circuit usually used with the omegatron is shown in Fig. 1 and it is apparent that no provisions are made for regulating this emission current. It was quickly discovered that regulation of the input filament power does not result in emission regulation. This is not surprising since emission current is determined by many parameters such as pressure, condition of the surface of the filament, change of focus of the electron beam due to hydrocarbon build-up and change of input power even within the $\pm 2\%$ rating of the regulators. Possibly this extreme sensitivity to input power is the result of the fact that the recommended beam current is only one microampere, and a very slight change of temperature of the filament causes comparatively large changes in this current.

In actual operation, the electrometer used in the collector circuit had an input impedance of $10^{10} \Omega$ and a full-scale sensitivity of 30 mv. At these settings, the zero drift amounted to about $\pm 15\%$ of full scale over a period of several hours. The emission current varied over a like period of about $\pm 40\%$. As expected, the peaks and valleys of the zero drift corresponded to the emission current changes. This evidence suggested some type of emission control was necessary.

The type of emission control selected was originally designed for controlling the greater emission current of ion gauges (Steckelmacher and Van der Meer 1950). Modifications were therefore necessary in order to achieve control of the one microampere of current required by the omegatron. A safety feature was also incorporated in the circuit so that component failure would not burn out the omegatron.

The final circuit is shown in Fig. 2. It operates in the following fashion. The beam current (collected by the target) flows through resistor R_1 causing a voltage drop of 0.1 v across it. This voltage is applied to one input of the differential amplifier. Resistor R_2 is adjusted so that 0.1 v also appears at the other input, thus resulting in no output from the amplifier. A variation of beam current will now cause the output of the amplifier to be increased or decreased, since the input voltage developed across R_1 will vary with the beam current. The output of the amplifier will cause the plate current of V_1 and V_2 to increase or decrease, causing a change of current in the filament circuit. This change of current in the filament circuit increases or decreases the filament temperature, increasing or decreasing the electron emission collected by the target and thus completing the feedback loop. The amplifier gain is now adjusted to a value just under the point at which instability occurs. In the present case, this was about $\times 1000$, which resulted in emission control somewhat better than $\pm 3\%$.

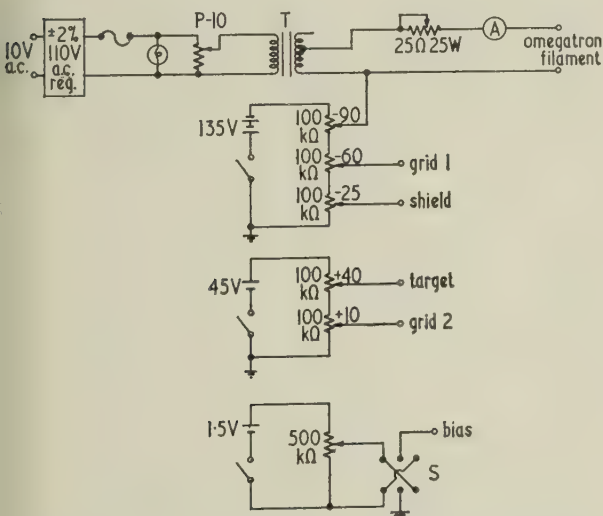


Fig. 1. Original omegatron filament and bias supply. ± 6.3 v filament transformer; S, double-pole, double-throw switch.

VOL. 38, SEPTEMBER 1968

Two simple methods for spot welding wires

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S. received 10th May 1961

Abstract

Two simple pieces of spot welding equipment are described, together with their application to the welding of wires with a wide range of compositions and sizes.

Introduction

THE relatively large electrodes used on most commercial spot welding machines make it difficult to precisely weld small diameter wires. In addition the welding pressures are generally high and can lead to severe distortion of the region of the welds. The techniques described here were initially developed in order to overcome these difficulties, and so permit the use of small diameter wire specimen material for studies of solid state transformations in steels (Radcliffe and Rollason 1959, White and Owen 1960). As these were investigated by measuring the attendant change in electrical resistance, it was necessary to weld on to the specimen accurately positioned potential leads. Usually the specimens were 0.010 in. in diameter and the leads were of 0.002 in. diameter chromel wire. Small diameter leads were necessary to minimize heat conduction from the specimen during the periods when it was heated by means of its own critical resistance.

Experimental methods

The method of welding used for this work has been termed resistive welding (Hickson 1940) and fusion between the two wires is brought about by an arc struck between them. In principle, using an arc formed by the discharge of a capacitor, has been applied to commercial spot welding machines and on an experimental scale, to the butt welding of wires (Stover 1960). In the present application both capacitor discharge and fuse limited arcing have been used.

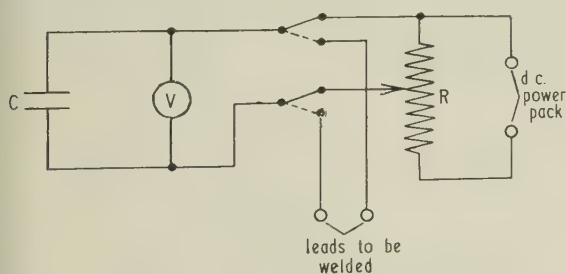


Fig. 1. Circuit diagram of the capacitor discharge apparatus.

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The circuit for the capacitor discharge apparatus is shown in Fig. 1. In order to make a weld, the capacitor is first charged to a voltage appropriate to the smallest wire to be welded, the limiting voltage being controlled by the resistance R . The double-pole-double-throw switch is then closed and simultaneously the two wires are touched together. The excellent welds which can be formed using this technique are illustrated by the micrograph, shown in Fig. 2, of the interface between a 0.002 in. diameter chromel wire and a 0.010 in. diameter plain carbon steel wire.

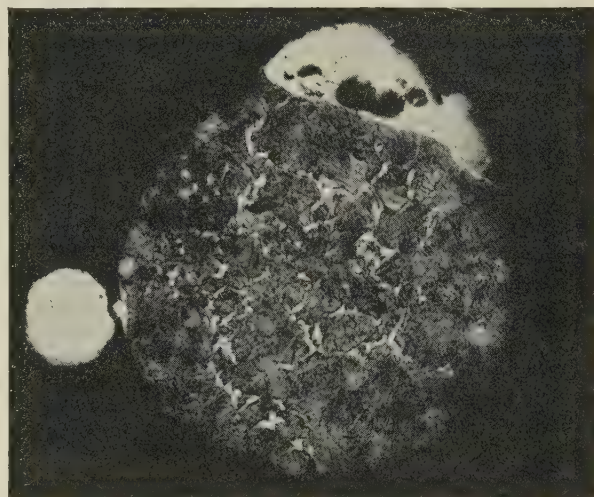


Fig. 2. The interface between a 0.002 in. diameter chromel lead and a 0.010 in. diameter plain carbon steel wire. $\times 200$.

Varying the capacity or the charging voltage of the capacitor alters the intensity of the discharge. As shown in the Table, use has been made of this fact to extend the technique to a variety of wire sizes and compositions.

The compositions and diameters of wires welded using the capacitor discharge technique

Diameter and composition of the wires	Capacitor capacity (μF)	Charging voltage (V)
0.002 in. chromel and alumel to 0.010 in. plain carbon and low alloy steels	128	30
0.010 in. platinum and platinum-10% rhodium to 0.040 in. uranium	180	100
0.060 in. tantalum and tungsten to 0.125 in. iron-aluminium alloys	1200	400

In general one wire is fixed in a jig whilst the other is held in the hand by means of insulated tweezers. When welding heavy gauge wires this method could not be used because of the intensity of the arcing. Instead, both wires were held in jigs one of which was fixed and the other free to pivot, so that one wire could be made to fall on to the other. The weight of the pivoted jig ensured that the wires remained in contact after the arc had stuck.

The second method which had been used for welding small diameter wires together is that of fuse limited arc discharge. One of the wires to be welded is connected to an output terminal of a Variac transformer and the second wire through a fuse to the other terminal. With the Variac set to the appropriate voltage, the two wires are touched together, and the resulting arc brings about fusion.

The success of this technique lies in correctly fusing the circuit. The fuse must hold long enough to allow the welding to take place, yet fail more readily than the weakest

of the specimen wires in order to prevent its fusing once the weld has established circuit continuity. This limitation of the fuse makes it difficult to apply this method to the welding of very fine wires, for which fuse wire of a suitable ratio is not readily available and in general the technique lacks the versatility of the capacitor discharge method. However, it is useful for repetitive welding and in this connection the method has proved satisfactory for welding 0.009 in. diameter chromel and alumel leads to 0.020 in. diameter plain carbon steel wires.

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Notes and comments

Annual General Meeting of The Institute of Physics and The Physical Society

At the first Annual General Meeting of the amalgamated Institute of Physics and The Physical Society held in London on 4th July 1961, the following were elected to office:

President: Sir John Cockcroft; *Vice-Presidents:* Dr. V. E. Cosslett, Professor R. W. Ditchburn, Dr. W. H. Taylor, and Dr. J. Topping; *Honorary Treasurer:* Dr. J. Taylor; *Honorary Secretary:* Dr. C. G. Wynne.

Eight ordinary members of Council were also elected. This, the first elected Council of the amalgamated body, is very nearly the same as the 'caretaker' Council which has been in office during the first few months of the amalgamated body.

The report for 1960 which was adopted at the meeting, records that The Physical Society and The Institute of Physics ceased to exist as separate corporate entities on 5th July 1960, but for convenience and completion of the records their activities before amalgamation are included in this report with those of the amalgamated body.

The report records the holding of many conferences, symposia and other meetings, many of which were arranged by the Branches and specialist subject Groups. Details about the four scientific periodicals and the other publications

owned by the Institute and Society or for which it has been responsible are given in the report.

The report shows that at the end of the year the total membership in all grades was 8720. Of the 193 candidates who took papers in the Graduateship Examination, 63 were successful and of these 27 held university degrees and 35 a Higher National Certificate in Applied Physics. The number of candidates taking these examinations has continued to increase rapidly. In 1960, 46 technical colleges presented 194 candidates for the Ordinary National Certificate in Applied Physics and 29 colleges presented 355 candidates for the Higher National Certificate. During the year the Institute and Society issued a report entitled 'The Postgraduate Training of Physicists in British Universities' which created a good deal of interest, being referred to with approval in the scientific, educational and lay press.

Among the professional matters referred to in the report is the publication of the fifth survey of salaries received by members of the professional grades.

In order to ensure that the work of the Benevolent Fund of The Institute of Physics should be continued uninterrupted by the amalgamation the Board of that Institute in its first meeting appointed the amalgamated body as a Trustee of the Fund. During the year, the report states, assistance was given in nine cases to members or their dependants who had met with misfortune.

magnetic crack detector

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received 20th April 1961, in revised form 20th June 1961

Abstract

When using a gear simulation disk machine to perform experiments on pitting it is often desirable that pits or the cracks that precede pits should be detected at the earliest moment after their formation, if possible while the disk is rotating. A method for doing this, using a magnetic detector in the form of a tape recorder head, is described. The technique is also applicable to the detection of cracks in other components such as Wöhler fatigue specimens.

Introduction

PITTING, as found on gear teeth and disks used to simulate gear tooth contacts, is often preceded by small cracks, say 0.005 in. to 0.010 in. across by 0.015 in. deep, which have the characteristic shape of a V and grow over a period of 10^4 to 10^5 revolutions to become pits (Dawson 1961). When doing experiments in a disk machine such as that described in the above reference, it is sometimes desirable to detect these cracks as early as possible, preferably without having to stop the machine, since this affects the steady state temperature of the disks. This note describes one method for doing this.

Technique

When a steel disk with a central hole has a copper bar passed through this hole, and a large current is momen-

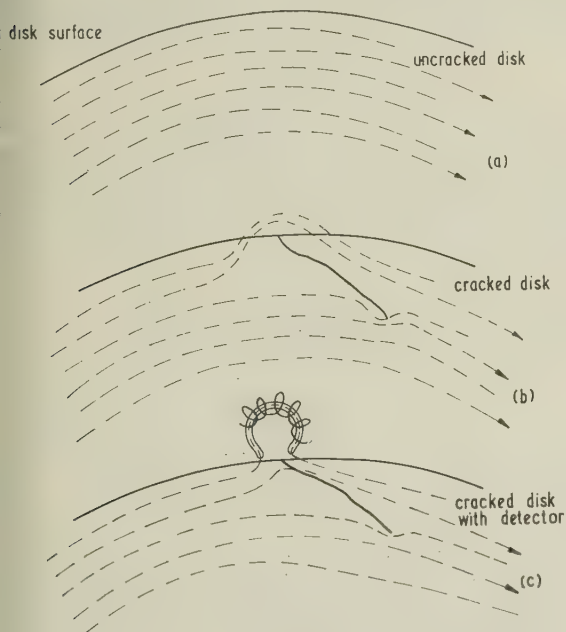


Fig. 1. Magnetic field in a disk.

tarily passed through the bar, a residual circular magnetic field is set up wholly within the disk (Fig. 1(a)). Later, if a magnetic discontinuity such as a crack appears in the surface of the disk, the lines of magnetic force that would have passed through the crack region are in part crowded around the tip of the crack and in part passed around and over the mouth (Fig. 1(b)). If the lines of magnetic force passing through the air are offered an easier path, such as a mumetal core, they will, in general, follow this easier path (Fig. 1(c)). When the disk is rotating, the rapid rise and fall of flux through the mumetal as the crack passes can be made to generate a voltage in a winding around the core, which can be displayed on a cathode-ray oscilloscope.

Apparatus

In these particular experiments the crack detector head was constructed as in Fig. 2; 600 turns of 0.0027 in. diameter

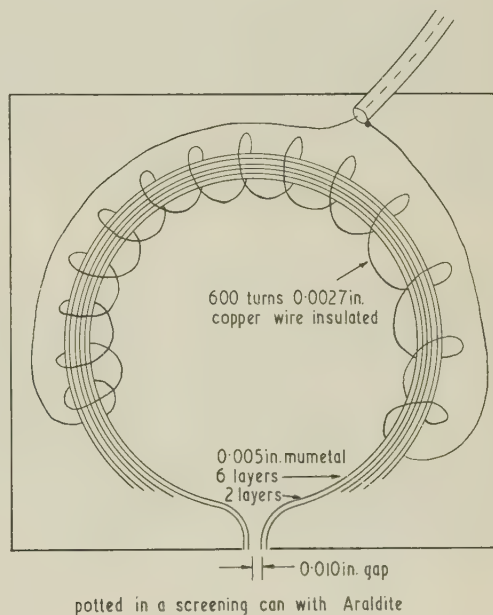


Fig. 2. Detector head.

copper wire were wound on a core consisting of six layers of 0.005 in. mumetal tapered down to two layers at the sensing point. The gap at this point between the two limbs of the core was about 0.010 in.

In order to test this pick-up a chordal slice was cut from a $3\frac{1}{2}$ in. diameter disk of 3% CrMo steel and then stuck back with Araldite, a thin spacer keeping one end apart 0.00125 in.

The gap at the other end was about 0.00003 in. as measured on a microscope. The resulting voltage, photographed on a Cossor oscilloscope, is shown in Fig. 3, the disk being rotated at 860 rev/min and the pick-up held approximately 0.005 in. from the surface. The 'blips' corresponding to the two simulated cracks can be clearly seen.

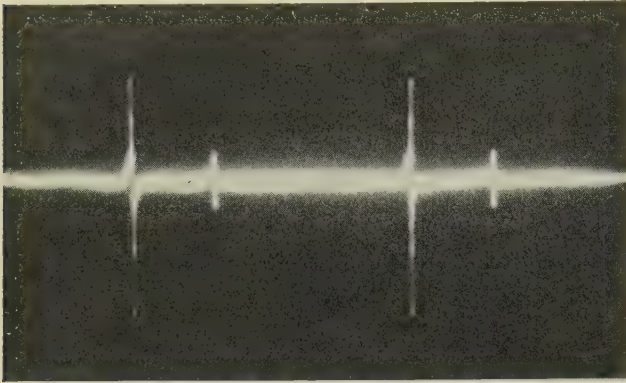


Fig. 3. Signal from simulated cracks. The larger 'blip' is approximately 5 v peak-to-peak.

Practical application

In a disk machine

This technique has been used on a number of disk tests as described by Dawson (1961), the disks being previously magnetized by passing 3600 A through the central hole.

It has been found that it is not always necessary to pre-magnetize the specimen and that often the larger cracks and pits can be detected either through residual magnetism in the disk or possibly due to the earth's magnetic field. However, the sensitivity under these conditions is much reduced, perhaps by a factor of ten. It has also been possible to detect smaller cracks by placing a permanent magnet somewhere near the pick-up head, the stray field being responsible for detection. It is important that under these conditions the field does not saturate the pick-up head. In general, noise is greater than with the pre-magnetized disk.

Other applications

Since the sensing head responds to changes in magnetic field with time, it can be used to detect circumferential cracks running part of the way around a rotating Wöhler fatigue specimen. The gap in the head may be set in the same plane as a crack; or to avoid having to position it too accurately in the axial direction, it can be set at, say, 45° to the crack. This does not seem to reduce the sensitivity much and allows a length of specimen to be covered at one setting. If the crack were perfectly straight, of uniform depth and in a plane at right angles to the axis of rotation, two 'blips'

should appear on the oscilloscope screen per revolution of the specimen; one for the start of the crack and the other for the end. In practice cracks are not perfectly straight and the cracked part of the circumference therefore produces a band of 'mush' on the screen (Fig. 4).

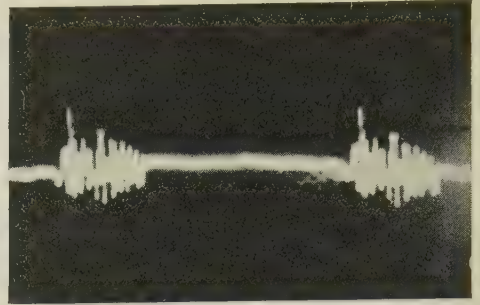


Fig. 4. Signal from Wöhler fatigue specimen crack, 1.8 in. long $\times$ 0.77 in. deep, in a mild steel specimen 2 in. diameter.

It is also possible to detect cracks in non-rotating parts by sweeping the head manually over the surface. However, the absence of a repeating pattern, unless a mechanical repetitive oscillator is provided to move the head, makes the oscilloscope display much less convincing than for a rotating specimen.

In these other applications, owing to the shape of the specimen, and often the absence of a central hole, the magnetic field is best provided by a permanent magnet.

The smallest crack detectable will depend upon the background noise and hence the surface finish of the specimen. Both Figs 3 and 4 were taken with lathe turned specimens with a roughness of about 30 μ m. C.L.A.

Conclusion

It has been found possible to detect very small cracks and pits in rotating disks using a primitive tape recorder head and cathode-ray oscilloscope.

Since the sensing head is capable of responding to circumferential cracks in rotating shafts, the technique also has applications in fatigue testing.

Acknowledgments

The author would like to acknowledge the help he received from Mr. A. H. Logan, and to thank Sir W. B. Jackson, Director of Research and Education, Associated Electrical Industries (Manchester) Ltd., for permission to publish this paper.

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Method for establishing a liquid column of graded density

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received 5th June 1961

Abstract

A simple technique has been devised to overcome the uncertainties and empiricism of the diffusion method of setting up a liquid column of graded density. This permits overall density gradient of the liquid and the density at any point within the column to be calculated before the column is set up, allowing considerable precision in separation of particles and in their density determination. Greater flexibility in the form of the column is possible, including the introduction of steps in the density gradient of the liquid.

A COLUMN of liquid graded in density is frequently used as a method of separating and determining the density of finely divided materials. Gradation of the column is achieved by the gradual diffusion of high and low density concentrations of a solution within the column, a procedure which is slow and which results in a column of unknown characteristics.

Figure 1 shows a simple apparatus which enables the rapid establishment of a column of liquid graded in density and having controlled characteristics.

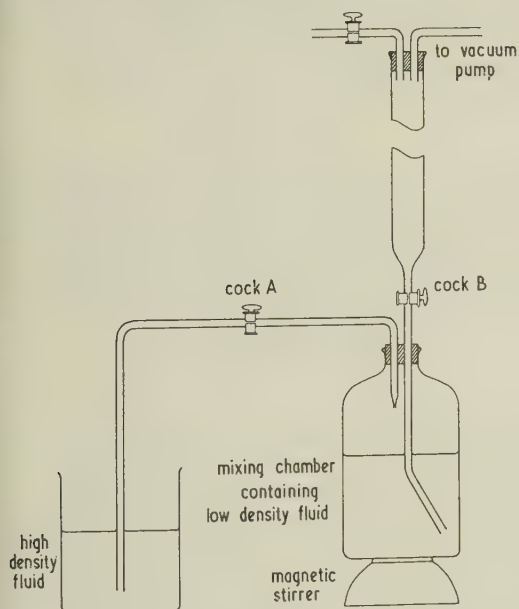


Fig. 1. Apparatus used for setting up a liquid column graded in density.

Upon subjecting the empty column to reduced pressure, low density liquid is drawn through cock B and replaced by high density solution from the beaker. Gradual and even increase in the density of the liquid in the chamber, and therefore of the liquid drawn into the

column, is ensured by continuous mixing with an electromagnetic stirrer. The liquid rises steadily up the column, there being very little disturbance by the inflow at the base. When the vertical tube is filled, cock B is closed and the column is ready for use as a means of separation or density determination. The time taken to establish the column is in the order of 10 to 15 minutes, being controlled by the rate at which the solution can be allowed to enter the base of the column; this depends upon the steepness of the gradient which it is desired to establish.

Providing there is no appreciable volume change upon the mixing of the two known starting solutions, which are selected with reference to the density range required for the separation of the material, the gradient and the density of the liquid at any point within the column may be calculated from the relationship $P_h = e^{-Ah/v}$, where P_h is the proportion of the original low density component in the solution at a point distant h from the top of the column, A is the cross-sectional area of the column and v is the volume of the low density liquid in the chamber.

If one litre is chosen as the total intended volume of the column, the tube which will contain the suspension fluid should be graduated volumetrically into 100 ml. portions; the density of the suspension fluid at each of the graduations

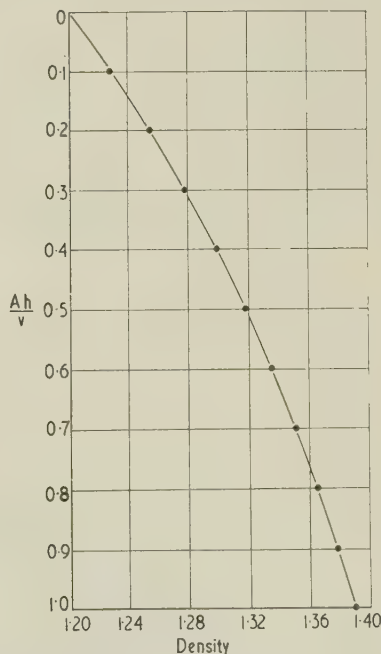


Fig. 2. Density profile in a liquid column formed from a low density solution of 1.2 g ml^{-1} and a high density solution of 1.5 g ml^{-1} .

may then be calculated and the density profile for the column determined. A typical profile is shown in Fig. 2, for which a low density liquid of density 1.2 and a high density liquid of density 1.5 were used, one litre of the liquid being present in the chamber, equal to the volume of the filled column. The determination of the density at a point 400 ml. below the top of the liquid column may be taken to illustrate the form of calculation.

$$P_h = e^{-Ah/v} = e^{-4/10} = 0.67.$$

The suspension fluid at this point is therefore made up of 0.67 parts of density 1.2 and 0.33 parts of density 1.5, giving a density at a level 400 ml. from the top of the column of 1.299 g ml⁻¹.

It is convenient to graduate the tube permanently and to fill it to the same point on every occasion; the volume of the liquid above each of the graduations then being known, the calculation of the density profile is simplified and the density at any point within the column may be obtained.

The density at the base of the column will always be less than that of the initial high density solution and this restricts the use of the column to lower density materials than is the case with the diffusion column where the saturation density of the suspension fluid is the limiting factor. This drawback may be minimized by reducing the volume in the chamber relative to the volume of the column, resulting in a basal density close to the maximum for the saturated solution, but under such circumstances the gradation of the column will deviate markedly from linearity.

Using a volume of liquid in the chamber equal to that in the column, controlled density gradients of less than 0.001 g ml⁻¹ cm⁻¹ have been established in a tube about 1 metre in length and 5 cm in diameter; this permits very accurate separations to be obtained.

Although the density gradient in the column is not linear the variation is known and the density of the liquid at any point within the column may be calculated from the relationship given above; this cannot be undertaken in a column established by diffusion.

The use of a controlled method for procuring the gradation permits a wide variation in the form of the column and its preparation for specific separations; it also enables a 'stepped' column, i.e. one containing discontinuities in the density gradient, to be established. This is effected by the following procedure; close cock A and after the removal of a quantity of low density solution from the chamber, close cock B, open cock A, and the high density solution is drawn into

the chamber by the residual vacuum. When cock B is reopened and liquid again drawn into the column, a sharp discontinuity will be present between it and the liquid already in the tube. The procedure may be repeated at intervals during the establishment of the column so that the continuous variation is replaced by a series of steps at predetermined density levels. The breaks between these have been observed to remain sharp for 2-3 days; a continuous graded column will remain stable for periods in excess of one month.

Graduation of the glass tube containing the liquid column together with a knowledge of the densities of the initial solutions, permits the discontinuities to be created at known values of density. Particles sinking down the column will collect at the discontinuities, all those having densities within the selected limits concentrating at one horizon and all other material being rejected. This permits fractionation of the sample, the limits are selected before setting up the column and the fractions occur as separate distinct bands within the column. The concentration of particles into bands facilitates removal where only small quantities of the sample are available.

Particles are extracted from the column by removing the chamber and draining the contents through cock B, the required portion being collected in a Buchner funnel, washed and dried. If it is desired to remove one specific band from the centre of the column, this is best achieved by the insertion of a polythene tube from the top, removing the fraction by suction; rubber tubing is too prone to collapse.

The rapid setting up and the predictable characteristics of the column established by the technique outlined above are advantages over the normal diffusion method. Very low gradients can be accurately controlled, thus permitting precise separation and accurate density determination. The introduction of discontinuities widens the scope of the density column technique, allowing concentration of a given fraction of the sample in the column and the simultaneous separation of two or more fractions within the same column.

Acknowledgments

Acknowledgment is made to the National Coal Board for a grant in aid of the research. The views expressed in this paper, however, are those of the author and not necessarily those of the Board. The author also gratefully acknowledges the assistance of Mr. J. Lee, Dr. D. G. Murchison and Dr. P. H. Roberts in the preparation of this paper.

Device for the accurate reproduction of liquid levels and some applications

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received 11th April 1961

Abstract

It has been found that a simple suction device can be used to reproduce liquid levels to a very high degree of accuracy. Application of this discovery to level control, collection of liquids under constant head and to the measurement of volume of large objects is discussed.

1. Basis of method

A tube drawn out in the form of a jet (see Fig. 1) is placed at a liquid-gas interface and suction applied then liquid is drawn up the tube until a break point occurs at which no further liquid is drawn up. This break point is only slightly affected by the suction rate and it has been found that the liquid level after the break is very constant. The accuracy

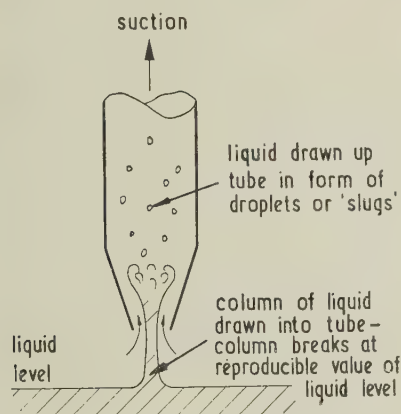


Fig. 1. Principle of operation.

The reproduction of the level was tested as follows. A glass jet was drawn out and clamped in a retort stand which was placed in a marked position on the bench. A 2½ in. diameter beaker containing water was placed underneath the jet—also in a marked position on the bench—and suction applied on the jet until no further liquid was drawn up. The beaker was removed and weighed and the experiment repeated many times. Deviations from the mean weight could be related, by calculation, to deviations from the mean liquid level. For a series of about 30 tests the maximum deviation from the mean was 35 microns and the standard deviation was 17 microns. This performance could undoubtedly be improved by more careful control of the relative positions of the beaker and jet, but the figures are indicative of the precision available even without such adjustments. The reproducibility of the liquid level will be affected

by the condition of the meniscus at the side of the vessel—variations from this source could be minimized by using a vessel of as large a diameter as possible and by using liquids which readily wet the material of the vessel wall. The device has been applied in several ways and these are discussed below.

2. Applications

2.1. Liquid level control in constant flow systems

The suction method is useful in level control as it is free from the usual fluctuations—caused by surface tension effects—observed in overflow devices. It is most convenient, however, to use the device as a secondary controller and to feed it in turn from an overflow device which accepts more easily large increases of input flow. Valve V (see Fig. 2) is

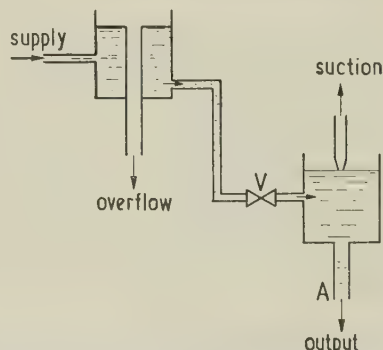


Fig. 2. Level control.

adjusted so that the suction device is operating correctly. The potential at A is constant to a high degree of accuracy and the combined device does not require very much total height.

2.2. Volume measurement of solids

The need occasionally arises for the measurement of the outside volume of solid objects. This can be achieved by loss-of-weight methods using a beam balance but often a suitable beam balance is not available. Using the suction technique and an ordinary set of laboratory scales (e.g. the Towers balance which weighs to 0.1 g) a convenient and accurate estimate of the volume can be obtained as follows. A beaker is filled with liquid of known density and placed in a marked position on the bench. A suction jet is also mounted in a fixed position above the beaker and the level is sucked down to the 'break-point'. The beaker is then

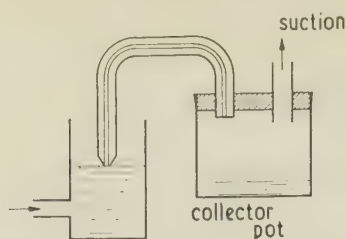


Fig. 3. Collection from constant level.

weighed. The object whose volume is required is then weighed and immersed in the liquid; the level is reset using the suction jet and the beaker and contents reweighed. The volume of the solid is readily calculated from the results.

This technique was used very successfully for the measurement of the volume of glass ampoules used in measurement of the solubility of xenon in bismuth (Hewitt, Lacey and Ly, 1959, *Atomic Energy Research Establishment Report CE/R 2638*).

2.3. Collection of liquid from a constant level

The liquid taken up from the constant level can be easily collected as shown in Fig. 3. Small volume changes at the source can be measured by measuring the amount collected in the collection pot. This technique was found very useful in some mercury flow experiments (Hewitt 1958, *Atomic Energy Research Establishment Report CE/R 2763*). Here it was necessary to collect minute flows of mercury through capillary the end of which had to be submerged and at constant pressure.

Notes and comments

Conference on the physics of semiconductors

The Institute of Physics and The Physical Society, on behalf of the International Union of Pure and Applied Physics and the British National Committee for Physics, is arranging an International Conference on The Physics of Semiconductors which will be held at the University of Exeter from 16th to 20th July 1962. The Conference is planned to follow the previous sequence of Conferences on the physics of semiconductors which were held in Reading in 1950, Amsterdam in 1954, Garmisch in 1956, Rochester in 1958 and Prague in 1960.

Accommodation will be provided in Halls of Residence at the University. Further information regarding the Conference may be obtained from the Administration Assistant, The Institute of Physics and The Physical Society, 47 Belgrave Square, London, S.W.1.

Symposium on electron spin resonance

The Chemical Society will hold a Symposium on electron spin resonance at Queen Mary College on Thursday, 2nd November 1961. Further information may be obtained from The Chemical Society, Burlington House, London, W.1.

The properties and applications of 'K' Monel alloy

We have received a copy of a new publication on the properties of 'K' Monel nickel-copper alloy. It consists mainly of charts and graphs on the physical and mechanical properties of the alloy with sections on the available forms and applications.

The publication is obtainable free on request from the Publicity Department, Henry Wiggin & Company Limited, Thames House, Millbank, London, S.W.1.

New publications of the National Bureau of Standards

We have received notice of the following new publications of the National Bureau of Standards: *Atomic Energy Levels in Crystals* by John L. Prather, National Bureau of Standards Monograph 19, 84 pages, price 60 cents. This monograph presents a theoretical study of the sharp line absorption spectra of crystals. *Corrected Optical Pyrometer Readings* by E. E. Poland, J. W. Green and J. L. Margrave, National Bureau of Standards Monograph 30, 74 pages, price 55 cents. This table can be used to convert the observed temperature to the true temperature, taking into account the effective emissivity of the material, or conversely to determine the effective emissivity if the true temperature is known. *Ideal Gas Thermodynamic Functions and Isotope Exchange Functions for the Diatomic Hydrides, Deuterides and Tritides* by Les. Haar, Abraham S. Friedman and Charles W. Beck, National Bureau of Standards Monograph 20, 271 pages, price \$2.75.

These monographs may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.

Canadian Nuclear Technology

We have received notice of a new Canadian publication *Canadian Nuclear Technology*, which is published quarterly starting from June this year. It will report on significant scientific achievement in Canada and throughout the world. An editorial advisory board, consisting of senior professional men in the nuclear industry, will referee the technical editor content of the journal. Further information may be obtained from MacLean-Hunter of Canada, 30 Old Burlington Street, London, W.1.

Ice point apparatus for hot climates

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received 2nd May 1961

Abstract. In hot climates, the conventional ice point apparatus is unable to develop a temperature gradient near the bottom, when the ice melts. This has been overcome by providing a false bottom of wire cloth and locking cold water vapours for some distance away from this screen.

Details of a suitable apparatus are given together with the procedure adopted at the National Physical Laboratory, New Delhi, India to obtain a stable ice point.

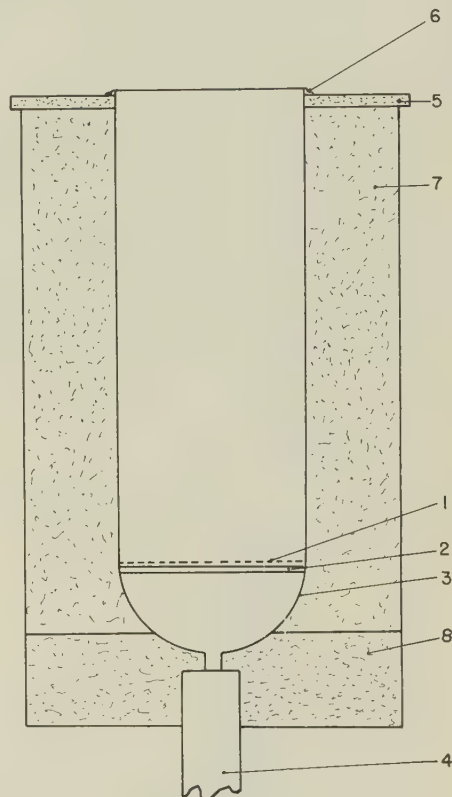
The ice point apparatus is an essential element of any precision thermometric measurement because ice point is used as a reference point in electrical pyrometry and as a check point in resistance thermometry as well as in liquid-in-glass thermometry. The ancient 'funnel method' has been replaced either by a large, well insulated porcelain jar provided with a drain tap, or by a double-walled glass jar (A.S.T.M. 1955). Though not so handy, even glass cells sealed with pure water at atmospheric pressure (Thomas 1934) and triple point of water cells (Stimson 1945) are being used as fixed points for very high precision work. The triple point of water cell, however, gives a temperature which has been assigned the value (Hall 1955, Bansal 1961) $+0.01^\circ\text{C}$. The methods also require some type of jar filled with ice.

There is no difficulty in using the jars in cold countries. In hot climates, such as in Delhi, where summer temperatures inside the rooms may sometimes rise above 40°C , the melting of ice is rather too quick even in a double-walled jar and ice starts floating on the water. A large vertical temperature gradient develops in this water since it is not stirred. The bottom of the jar can obviously reach as high a temperature as $+4^\circ\text{C}$ due to the anomalous thermal expansion of water. It is well known that the bottom of the thermo-sensitive elements gradually approaches this water temperature as time proceeds. The ice shell enclosing these elements then no longer remain dry. The wet ice has large water molecules entangled in it and so every part of it is not at 0°C . This makes the ice point observation uncertain and unstable, especially in continuous temperature measurement and for long work.

In order to avoid the thermo-sensitive element contacting the water level, the arrangement shown in the Figure has been developed. A copper wire cloth 1 of 100 mesh (about $0.2 \times 0.2\text{ mm}$ aperture) is fitted on to a wire annulus 2, by stitching it all round with a suitable copper wire. This annulus is allowed to rest about 4 to 10 cm above the bottom of a round bottomed glass jar 3. The bottom of the jar opens up by a long rubber outlet 4. A flange of cement asbestos sheet 5 is cemented at 6 near the top of the jar, to avoid seeping of ice and water along the sides. The whole equipment is supported on a cork slab 8 and a stand (not shown), in such a way that a quilt of glass wool 7, can be wrapped round it when required.

Commercial ice, crushed into lumps with dimensions of a few centimetres, is placed in running water for a few minutes to make the temperature constant over the volume, and then reduced to 2 to 3 mm size in a clean cloth. The apparatus,

topped with this ice, is rammed. Tap water is run freely through it, from top to bottom, and air pockets are filled in by continuous ramming, until the water, which was



Ice point apparatus. 1, copper wire cloth 100 mesh; 2, annular frame for wire cloth; 3, round bottom jar with a spout at the bottom; 4, rubber tube; 5, asbestos cement sheet; 6, cement; 7, glass wool; 8, cork slab.

coloured due to dust and impurities, becomes clear. The tap water is then stopped and the outlet of tube 4 is supported in the stand in such a way that some water always remains in the bottom of the jar, but the water level always remains at least 2 cm below the wire cloth frame. After this, the melted ice drips through the wire cloth and maintains cold water vapour in the space below. The excess water automatically drains out through the rubber tube 4 without touching the wire cloth. The thermo-elements are then inserted in the usual way, keeping them as far away from the wire cloth as convenient. The whole equipment is then wrapped with the quilt of wool and allowed to stabilize for 15 to 30 minutes before use. The jar has to be topped with the ice and the whole operation repeated when sufficiently large amount of ice has melted off.

The arrangement can be depended upon to give a stable

temperature with a precision of the order of 0.01°C . It eliminates the possibility of thermo-elements ever touching the water level or the zone of temperature gradient.

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Laboratory method for making small alumina crucibles

by I. LEVANONE, Ministry of Defence, Scientific Department, Tel-Aviv, Israel

MS. received 4th January 1961, in revised form 13th March 1961

The technique generally adopted in the laboratory for the vacuum evaporation of powdered materials requires small refractory crucibles made from fired ceramic cement. However, the powdered material is likely to be contaminated by impurities originating from the crucible material at the high temperatures usually required. An example is the vacuum evaporation of pure zinc sulphide—for luminescence purposes—at a temperature exceeding 1400°C . It would be advisable in such cases to use crucibles made from pure materials, which contain no bonding cements and which can be melted to a crucible form. A suitable material that complies with these requirements is crystallized powdered alumina, which can be formed into the required crucible shape by the technique described here.

The raw material (RR Alundum in crystalline form, 90-120-mesh (Norton Co., U.S.A.)), its surface roughly levelled (Fig. 1), is placed in a porcelain beaker and the

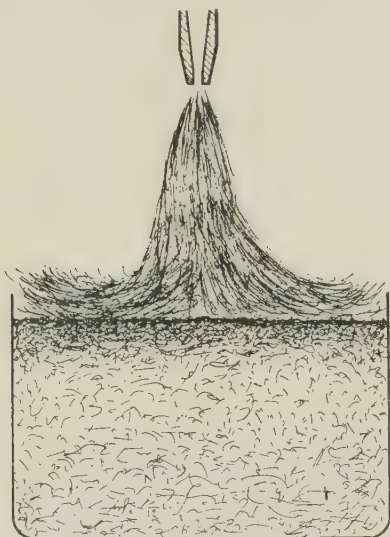


Fig. 1. Gentle heating of powdered alumina, using an oxy-gas blow-lamp.

surface gently heated by an oxy-gas blow-lamp, thus producing a sintered surface layer (which will prevent subsequent blow-out of the alumina powder). The gas flow into the blow-lamp is then increased considerably until a very high-temperature flame is obtained.

This flame when concentrated at one point on the sintered surface will form, in a short time, a large drop of melted alumina. The gas flow is then adjusted to give a thin short

flame and the burner is held as close as possible to the centre of the drop. The crucible shape will be formed by the flow (Fig. 2). Toward the end of the process the nozzle is brought to the surface level of the crucible.

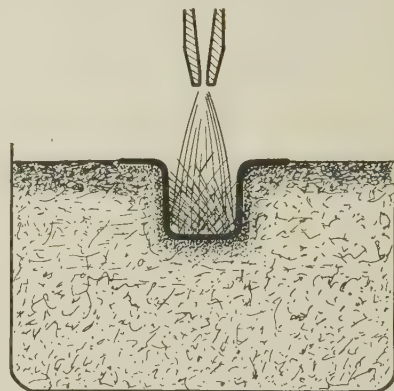


Fig. 2. Formation of crucible shape.

Owing to the high temperature the nozzle has to withstand it is advisable to use one made of stainless steel. If a brass nozzle is used it might be damaged during the process and the crucible itself would be contaminated.

With a normal glass blow-lamp the crucible obtained has a diameter of 10 to 15 mm, a height of 15 to 20 mm and 1 to 2 mm thickness. If an oxy-acetylene blow-lamp is used larger dimensions may be obtained.

The wall thickness can be controlled by the duration of the heating. With some experience and using alternative jets more complex shapes can be produced as shown in Fig. 3.



Fig. 3. Varying crucible shapes.

Large edges are normally formed in the heating process; they may have to be trimmed with a hard grinding stone.

Crucibles obtained by this method proved to be most satisfactory for the evaporation of zinc sulphide and have been actually used for hundreds of evaporation processes. From a practical point of view it may be noted that the crucible can be cleaned by boiling acids without damage and that it withstands temperatures up to 2000°C .

note on temperature measurement in high temperature x-ray powder cameras

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S. received 6th February 1961, in revised form 8th June 1961

the difficulties involved in accurate measurement of the specimen temperature in high temperature cameras are well known to those working in this field. Early experiences with the Unicam S150 camera suggested that some modification would be needed to make it more versatile and reliable in this feature. As Brand and Goldschmidt (1956) have pointed out, the chief source of error lies in the difference in heat lost by thermal conductivity from the thermocouple lead and from the specimen; the former being connected to the outside by two conducting wires, whilst the latter is usually mounted on an insulating ceramic rod. Other errors may arise from differences in emissivity of specimen and thermocouple as well as contamination of the thermocouple by metallic deposition (e.g. rhodium from the furnace winding) or alteration of its composition by selective evaporation. In order to reduce all these errors to a minimum, it is necessary to increase the surface area of the thermocouple junction relative to the cross-sectional area of the wire and to provide suitable shielding.

To improve temperature measurement in a camera of this kind, therefore, it was decided, wherever possible, that the thermocouple should be of fine wire (0.004 in. dia.) placed inside the specimen and forming the support for it. In practice, this is achieved by using fine thermocouple sheathing of 0.030 in. dia. having two 0.008 in. dia. holes down it to carry the wires. (This material, made of 'Sintox', was supplied by Lodge Plugs Ltd., Rugby.)

Figure 1 shows four ways of mounting the specimen. For

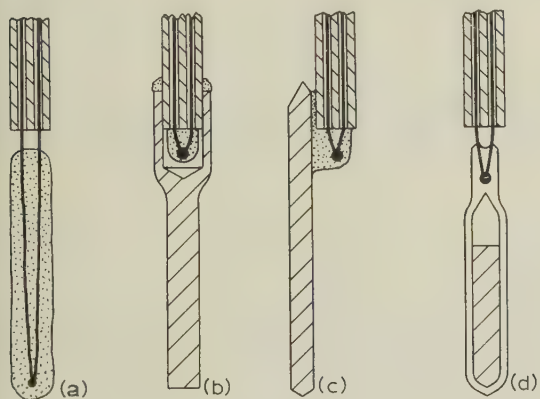


Fig. 1. Methods of mounting specimens on thermocouple, (a) non-reactive powders, e.g. refractory oxides, (b) machined metal specimens, (c) non-machinable specimens, e.g. fine wires or sealed off capillaries, (d) samples sealed off in capillaries with couple.

materials which do not react with platinum the thermocouple junction can be left protruding from the end of the sheath and the specimen then formed around the wires. (Lines corresponding to the thermocouple metals, if they appear on the film, may form a useful internal standard or check on the thermocouple composition.) In the case of reactive materials, particularly metals, the junction can be pulled

back and protected with a blob of alumina cement. If possible, a metal specimen, machined with one end of larger diameter, should be bored with a fine twist drill in a watch-maker's lathe to provide a recess in which to embed the thermocouple.

The most difficult types of specimens to mount are powdered samples which need sealing in thin-walled capillary tubing to prevent contamination or dissociation. However, it is possible, with some practice, to embed the thermocouple in the sealed-off joint and hence use the glass as a protective coating. Alternatively, the sealed off capillary can be cemented to the end of the thermocouple sheath.

Using the thermocouple as a specimen mounting necessitates more generous adjustments for centring (due to warping of the sheaths during manufacture) and height. Provision must also be made to allow electrical connections to the couple via a rotatable vacuum seal. The use of slow rotation (e.g. 1 revolution/hour) or 360° oscillation is more desirable than slip rings in the thermocouple circuit. The modifications made to the specimen holder and camera top are shown in Fig. 2.

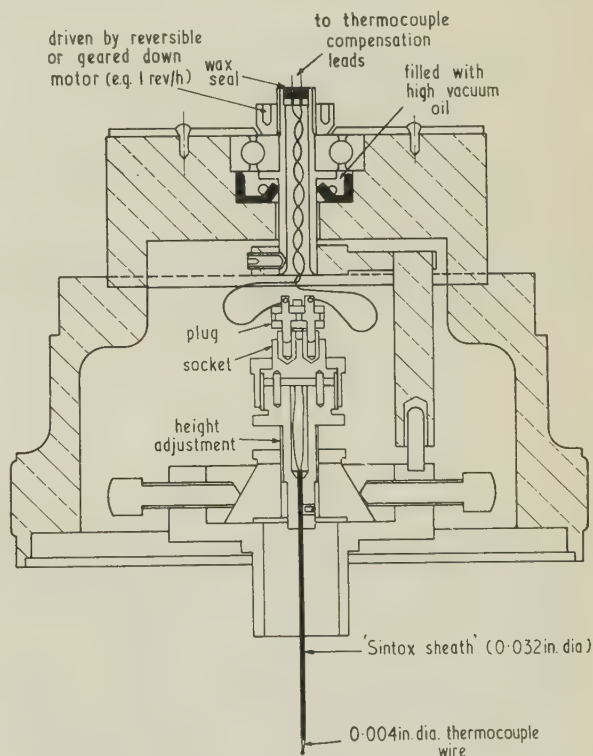


Fig. 2. Assembled top unit showing details of specimen holder and thermocouple.

Thermocouples are regarded as expendable and, with the present arrangement, replacing one is considerably easier than with the original couple which enters through the base

of the camera. This is now generally used only for temperature control and observed differences in temperature between the two couples have given further confirmation of the source of the discrepancies originally encountered. Since changing to the fine wire couple as specimen mount, no significant errors have been found (Johnson and Andrews 1956), whereas previously differences of between 50 and 100 deg c were common in the range 400–500° c.

Device for stabilization of gas flow

by J. NOVÁK and J. JANÁK, Czechoslovak Academy of Sciences, Laboratory of Gas Analysis, Brno, Czechoslovakia

MS. received 22nd March 1961, in revised form 2nd June 1961

The stabilization of pressure and hence of flow-rate in a gaseous medium is a frequently occurring problem. Usually a gas reservoir or a damping capillary (e.g. in the gas chromatograph made by Griffin and George, London) is inserted between the source of pressure oscillations (some type of pressure manostat) and the place where these oscillations must be removed. Such a method is not always entirely satisfactory, however, as may be shown by the theoretical analysis described elsewhere (Novák 1961). By using the analogy between electric and pneumatic quantities, a three-stage damping device has been developed which is illustrated in Fig. 1.

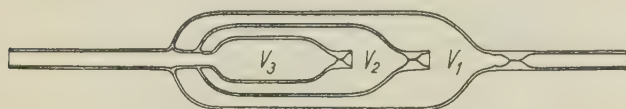


Fig. 1. Scheme of the three-stage device for stabilization of gas flow.

For a one-stage damping unit, the following relations can be derived for the amplitude P_1 and the phase shift ϕ of the outlet pressure wave in the gas.

$$P_1 = P_v \left\{ \frac{4\pi^2 f^2 O^2 V^2}{R^2 T^2} + \left(\frac{O}{O_K} + 1 \right)^2 \right\}^{1/2} \quad (1)$$

and

$$\tan \phi = \frac{2\pi f V}{RT} \frac{O \cdot O_K}{O + O_K} \quad (2)$$

where P_v is the amplitude of the inlet pressure wave, f the frequency of the pressure oscillations, O is the pneumatic resistance of the damping capillary in the damping unit, O_K is the pneumatic resistance of the following part of the apparatus (e.g. of the chromatographic column), and V is the volume of the pneumatic member.

Very similar relations for two-stage, three-stage or more-stage damping can be derived with the simplification that the pneumatic resistances of the damping capillaries $O_1, O_2, O_3, \dots \ll O_K$, and the first member in the denominator of the Eqn (1) is $\gg 1$.

The performance of the device was compared experimentally with the performance of the capillary and gas reservoir methods under similar conditions. In Fig. 2 are shown base-lines produced by a katharometer, which was coupled in the usual way into the chromatographic system. With

The author wishes to thank Mr. F. H. Saniter, O.B.E. Director of Research, for permission to publish this note.

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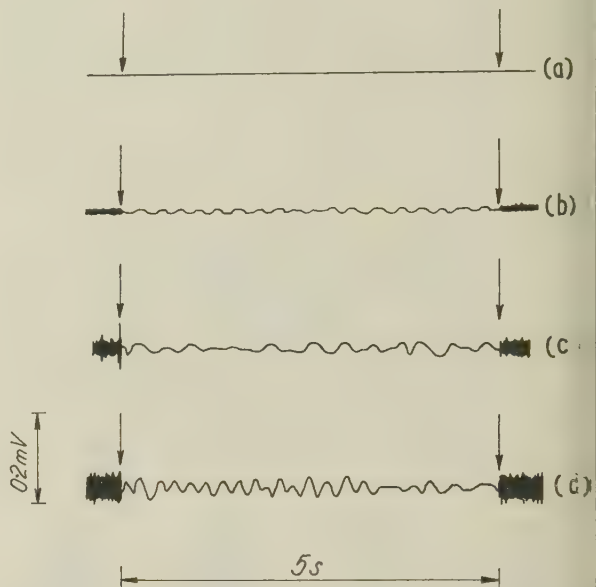


Fig. 2. Comparison of the damping effect (a) of three-stage stabilization device, (b) of even capillary tube with the same pneumatic resistance, (c) of volume-equalizer with the same volume, and (d) without any damping.

hydrogen at 1.3 ml./s, the inlet pressure on the chromatographic column was 788 mm Hg, and the outlet pressure 750 mm Hg. Oscillations were excited in the inlet side and showed an average amplitude $P_v = 20$ mm H₂O and a frequency of four cycles per second. In Fig. 2(a) the effect of the three-stage damping device can be seen with the volumes $V_1 = 88$ ml., $V_2 = 26$ ml. and $V_3 = 6$ ml., and equal contracting capillaries of pneumatic resistances.

$$O_1 = O_2 = O_3 = dP/dq = 76 \text{ atm. s mol}^{-1}. \quad (3)$$

Fig. 2(b) shows the performance of an even capillary tube (14.0 mm long and of 0.26 mm internal diameter) with the same pneumatic resistance as the whole device and with negligible volume. Fig. 2(c) illustrates the same experiment using a bottle ($V = 120$ ml.) with volume equal to the whole device and with practically no pneumatic resistance. The base line in Fig. 2(d) corresponds to the undamped state.

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The 'EEL' B.R.S. daylight photometer

P. PETHERBRIDGE, M.Sc., F.I.E.S., and WENDY M. COLLINS, B.Sc., Building Research Station, Garston, Watford, Herts.

MS. received 12th May 1961

In a recent letter to this Journal, Turner (1961) has referred to a similarity between his own daylight factor meter (Turner 1960) and one described by Koch and Kaplan (1952). Both meters bear similarities to one devised by Barnard in 1936, probably the first to use rectifier photocells in an instrument for measuring daylight factors.

It may be of interest that during 1956 another similar meter, now referred to as the 'EEL' B.R.S. Daylight Photometer, was developed at the Building Research Station, the basic circuit being shown below. This uses the same prin-

the portable meter does not readily lend itself to the measurement of daylight factors in models of room or building interiors. The limitation has been overcome in the present meter, at the expense of some degree of portability, by using separate indoor and outdoor photocells, as do the meters referred to earlier (Turner 1960, Koch and Kaplan 1952, Barnard 1936).

When the portable meter was first introduced, it was pointed out that it could not be used under conditions of rapidly changing sky conditions. Daylight factors measured under such conditions are in any case of doubtful value. In the present meter, the time interval between taking the outdoor and indoor measurements is reduced, but it is only in balanced-circuit type meters such as that of Turner or of Koch and Kaplan that this limitation, if it is indeed a serious one in practice, is completely met.

By taking advantage of currently available small but highly sensitive cosine-corrected photocells (Pleijel and Longmore 1952), daylight factors have been successfully measured in model rooms constructed to only 1/24 full size.

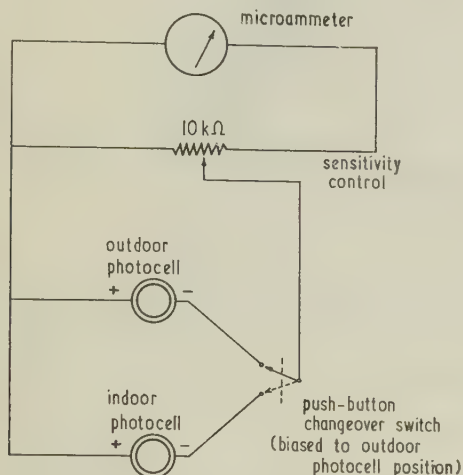
The meter is direct reading, as is the portable meter from which it was developed, and, by means of separate calibration curves, can also be used to measure indoor and outdoor illuminations and the luminances of relatively small patches of sky.

Acknowledgment

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ple of operation as an earlier B.R.S. portable meter (Longmore and Hopkinson 1954).

To achieve the high degree of portability required for this earlier meter, only one photocell was used for both the indoor and outdoor measurements. This introduced an additional limitation, not referred to by Turner in his paper, in that

Seal between silica tubing and glass apparatus

W. R. GEORGE, B.Sc., A.I.M., and R. V. WINKLE, Nelson Research Laboratories, The English Electric Co. Ltd., Blackheath Lane, Stafford

MS. received 9th June 1961

It is sometimes necessary to effect a joint between glass tubes and flasks and wide bore silica tubing as used in laboratory furnaces. Difficulties in producing a gas-tight seal are experienced due to the rough, sanded surface of these tubes, which also are often elliptical.

A simple solution is offered by using glass tubes of suitable diameter to slip inside or outside the silica tube. The smaller diameter tube is then bound with one inch wide polythene tape to make a snug fit in the wider tube. The seal is then made by heating the silica tube, with a flame, to about 200°C, when the polythene just melts. On cooling, the

polythene forms a gas-tight joint. For best results, the silica tube should be vertical during sealing and a ring of asbestos cord or tape used below the polythene to prevent it flowing out from the joint.

The seals described have proved satisfactory at temperatures up to 80°C on furnace assemblies, and are more durable than rubber compression seals of the 'O'-ring type, especially in highly corrosive atmospheres.

Thanks are expressed to Mr. J. K. Brown, Director of Research, for permission to publish this note.

Simple electric pantograph

by G. J. FRISONE, M.Sc., Rohm and Haas Co., Philadelphia 37, Pa., U.S.A.

MS. received 14th February 1961

The accumulation of a large amount of data by strip chart recorders and various other recording devices very soon reaches a point where the storage and handling problems become significant. The device described below was developed to function as a data-reducing or expanding instrument for the handling of recorded data from gas chromatography,

The operation of the device is extremely simple. The chart to be reduced is taped to the bed of the instrument, chart paper inserted into the recorder and the zero and span of the recorder set by the proper controls. After the zero and span have been set, the recorder pen is depressed and the curve to be copied is followed by the stylus. After the curve has

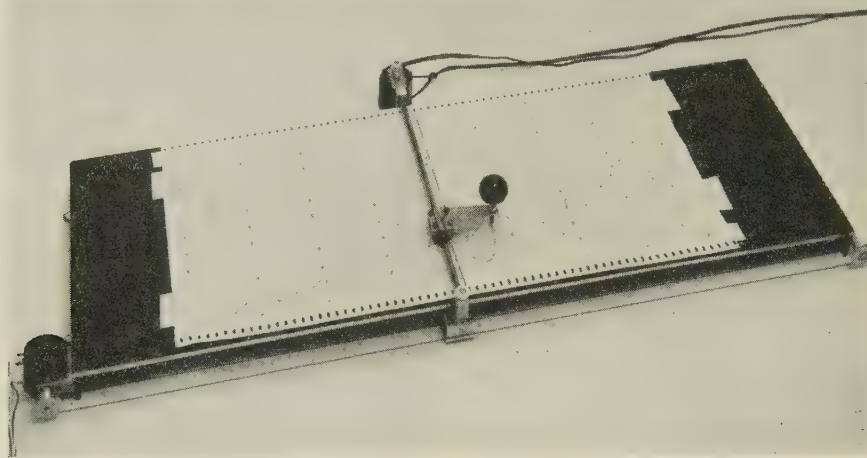


Fig. 1. Photograph of the electric pantograph.

polarography, ultra-violet spectroscopy, infra-red spectroscopy, thermo-gravimetric and differential thermal analysis. This device can also be used to plot different data on the same chart paper, thereby facilitating comparisons. There are several data-reducing and data-following instruments on the market, but these suffer from the standpoint of complexity and high cost. The main purpose of this instrument is to reduce or expand to a standard $8\frac{1}{2}$ in. $\times$ 11 in. chart all of the various sizes and shapes of continuously recorded data.

Figure 1 is an actual photograph of the device to be described and Fig. 2 is a schematic drawing of the electrical connections. Detailed engineering drawings of the prototype are available on application to the author.

The apparatus consists essentially of a simple manually operated x - y axis, to which are connected two ten-turn helipot potentiometers. These potentiometers could then be connected to an x - y recorder, which has a variable zero and variable span, or to other suitable apparatus.

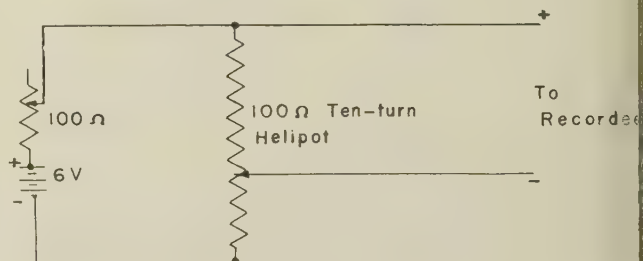


Fig. 2. Electrical connection for pantograph.

been copied the $x + y$ scales are traced, so that the reproduced curve and its axis will be in direct proportion to the original curve.

The author wishes to thank Mr. M. Bechta and on Research Mechanical shop for the many helpful suggestions on the design and construction of this apparatus.

Substitute for metal boats used in vacuum evaporation

by R. L. N. SASTRY, M.Sc.(Tech.), Electronics Research and Development Establishment, Post Box 108, Bangalore-1, India.

MS. received 12th June 1961

When metal boats are used as evaporating sources for evaporation on plastics, the latter tend to become overheated due to the large heat energy dissipated from the boat source. Conical wire baskets can be used but are unsuitable for evaporating salts and other materials which would run out of the basket. This difficulty can be avoided by putting a

small piece of foil of the same metal as the wire at the bottom of the conical basket between two turns of the wire. Magnesium fluoride has been successfully evaporated from a molybdenum basket prepared as above on to a Perspex substrate without overheating of the latter.

Objective astigmatism correction of the Elmiskop I electron microscope

M. A. SILVA, B.Sc., Aeon Laboratories, Ridgemoor Road, Englefield Green, Egham, Surrey

(S. received 9th May 1961)

This note describes a rapid method for setting the direction control of the objective stigmator of the Siemens Elmiskop I. One widely used method is to form a slightly overfocused image of a circular hole in a carbon film with the strength control of the stigmator turned to zero (Fig. 1(a)). Non-

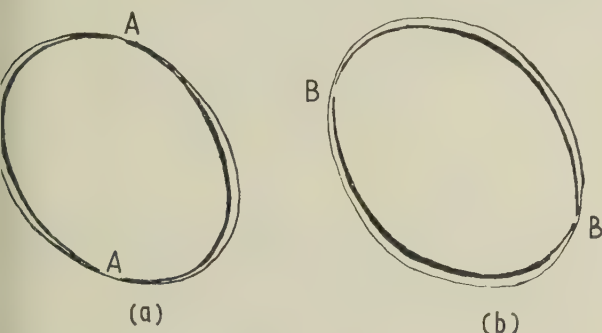


Fig. 1.

uniform Fresnel fringes are formed and the point A at which these are thinnest are noted as being an indication of the direction of the astigmatism of the instrument itself. With the strength control turned to maximum, the direction control is then adjusted until the new points of extinction of the fringe lie perpendicular to the points A (points B, Fig. 1(b)). The stigmator strength is then reduced until a fringe of uniform width is obtained.

The true criterion of orthogonality between Figs 1(a) and (b) is that the tangents to the circumference of the hole at points A should be perpendicular to the tangents at points B. This is difficult to judge on the final screen of the instrument with any but the most circular hole, since there is an automatic tendency to arrange the respective diameters at right angles to one another.

Allowance must also be made for the fact that the final screen has to be tilted for observation through the telescope. In general this has the effect of changing the apparent direction of the tangents, as may be seen in Fig. 2. In this figure, which is drawn for a screen tilted at 45° to the axis of the electron microscope, the rays reaching the final screen are assumed parallel for the sake of simplicity. All the coordinates of the circular hole C are increased in the ratio $\sqrt{2} : 1$ to form the ellipse C'. If A is a point of extinction formed in the same way as A of Fig. 1(a), then A' is the corresponding point in the image with the screen flat. The point on the circle having a perpendicular tangent is B' and the ordinate through this point intersects the ellipse at B, which is the true point sought, corresponding to B of Fig. 1(b). A false point B'' is found by drawing a tangent perpendicular to that at A. B and B'' coincide, however, if A' and A lie on either the vertical or the horizontal axis of the figure, and this can be used to provide a more accurate adjustment.

One of the cross wires of the Wray binocular magnifier

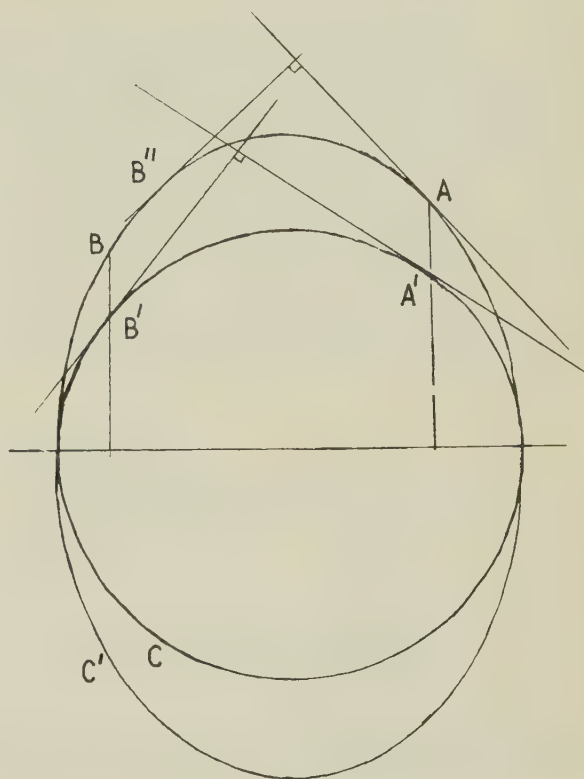


Fig. 2.

is first set parallel to the axis of tilt of the final screen. With the stigmator strength at minimum, the stage is manipulated and the image rotated by altering the strength of the projector lens until one of the cross wires lies as a tangent to extinction point A. The strength of the projector is then left unchanged and the direction control of the stigmator adjusted with the stigmator strength at maximum until the other cross wire forms a tangent to the hole at extinction point B, moving the stage as required. The stigmator strength is then reduced in the usual way. The projector is then returned to its normal strength. The change in projector strength has not been found on our microscope, to introduce a detectable change in astigmatism.

The difficulty caused by the raised screen can also be overcome without alteration of the projector strength. This is done by adjusting the objective lens when the stigmator strength control is set to maximum, until only a short section of the edge of the hole is overfocused. The centre point of the arc of overfocused fringe should then lie at the same point as the original point of extinction. It is thought, however, that when extinction points only are used, greater accuracy can be achieved.

The author wishes to thank Mr. A. W. Agar, Head of Aeon Laboratories, for helpful advice and criticism.

Locking tweezers made from a hypodermic needle

by D. I. JAMES, B.Sc., Grad.Inst.P., and W. G. NEWELL, Rubber and Plastics Research Association of Great Britain, Shawbury, Shrewsbury, Shropshire

MS. received 9th June 1961

Abstract. A stainless steel wire is fitted inside a veterinary needle. The end of the wire and the bent point of the needle form the gripping surfaces of a pair of tweezers. A camera cable release with a locking collar controls the position of the wire and enables the tweezers to be locked on to an object.

A veterinary needle and a camera cable release form the basis of a simple and easily made pair of tweezers which can be locked in any position. The mode of operation may be seen from Fig. 1. The plane end of a stainless steel wire, which fits exactly inside the needle, bears on the inside surface of the needle end which has been bent into a plane normal to the needle axis. A single bend is unsatisfactory (Fig. 2),



Fig. 1



Fig. 2

as the curvature of the corner prevents the two faces from meeting, but this is readily overcome by adopting the profile shown. In the absence of more refined equipment this is easily achieved by placing the needle end across a groove in a block of steel (Fig. 3), positioning a fine chisel-ended punch above it and then striking the punch lightly with a small

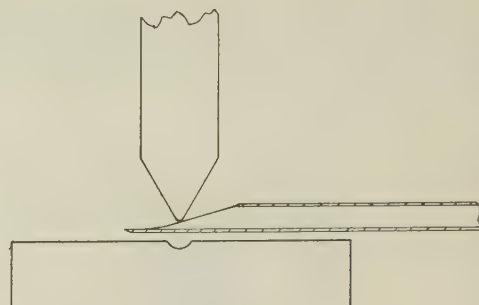


Fig. 3

hammer. The previously squared end of the wire may then be lapped against the flat surface at the bottom of the needle hole to ensure good contact.

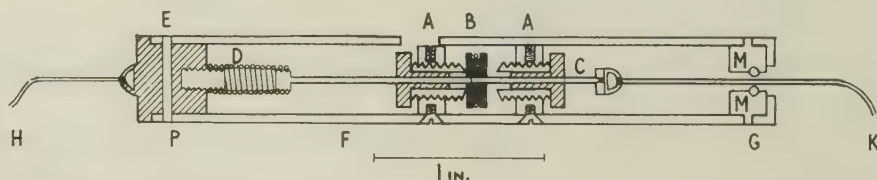
A small spring which bears against a disk soldered to the other end of the wire keeps the tweezers in the open position. If the tapered mount of the needle is tapped with a 4 mm thread it will be found that it will accept a camera cable release. The type fitted with a friction grip locking collar (not a locking screw) enables the tweezers to be set in any desired position and instantly released. No sizes have been given as the method is clearly applicable to any large needle. The limiting factor in size is the rigidity of the wire. (The smallest needle used at the Rubber and Plastics Research Association was a No. 14 Surgical Needle, but this has not proved as satisfactory as the coarser veterinary needle.) Perhaps it should be mentioned that this type of tweezers has been found unsuitable for very fine work, but coarse fibres about the size of a human hair may be handled with ease and firmly held.

Switch with floating preset differential

by W. NISBET, The Hannah Dairy Research Institute, Kirkhill, Ayrshire

There are certain applications for switches which have the facility of changing over automatically at any point of reversal in a signal derived from a varying process. The signal can have fluctuating amplitude and undulatory base line level. Such a process takes place in the respiratory action of an animal where flank movement can be used to operate a suitable device for remote indication of respiratory rate. The switch to be described was designed for this purpose and lends itself to similar instances where the process can be translated into lineal movement. The Figure is a detailed diagram of the switch, and its mode of operation is as follows.

When the unit is strapped round the trunk of an animal by cords H and K, inspiration causes rod C to move and extend the spring D. Expiration allows D to retract. The contact B which is friction-mounted on C thus alternates between fixed contacts A A, providing a single pole change over switch. The switch is used to charge a capacitor and then discharge it through a high speed relay to provide pulses whose duration is independent of respiratory rate or depth. Connection to the switch is made by fine insulated flexible wires soldered to A A and to the base of spring D. The wires (not shown) are brought out through holes drilled in the Tufnol plug E and thence to the recording apparatus.



g E is also drilled to take a dowel pin P which locks the
ch assembly to its Perspex housing F.

Contact B is a carbon rod bored to give a sliding fit on
ss rod C. The carbon is grooved round its circumference
take a phosphor bronze circlip and is then sawn di-
metrically in half. The two halves are fitted into the circlip
ch forces them to make good sliding contact on C and
takes up wear automatically.

The contacts A A are identical and are formed by boring
wired brass rod and tapering the contact ends to 60° (half
er). Tufnol bushes are then pressed into the screwed
s and bored to give a sliding fit on C. Both contacts fit
screwed brass annuli machined to slip into the tube F. The
uli are located in the tube by countersunk screws and

locking screws are fitted for setting the gap between A A.
For this adjustment, access can be had through a slot cut in
the Perspex tube. A rubber sleeve is fitted over this area to
prevent entry of dirt and to prevent electrical contact between
the animal and the locating screws.

An omnidirectional guide G is provided to afford free slip
of the cord K regardless of possible roll of the unit when
fitted to an animal. The guide consists of a Perspex housing
(cemented to F) and crossed pairs of parallel stainless steel
rods with cord K running through the central interstice. For
clarity only one pair of rods M M is shown.

Six similar counters have been in use regularly over a
period of about two years and have given reliable service for
counting respiratory rates up to 240/min.

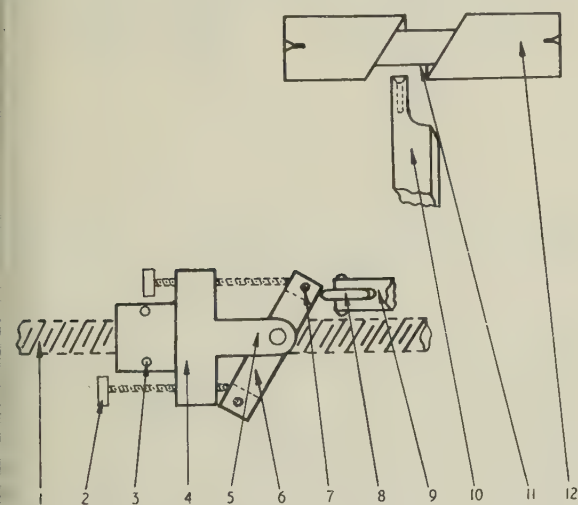
Cutting cam grooves by lathe

A. L. SIMS, University of Wales, Physiology Institute, University College, Cardiff

received 14th April 1961

One of the more difficult tasks facing the laboratory work-
shop technician, is that of cutting a cam groove in the outside
surface of a metal cylinder, so that a follower placed in the
groove can be made to oscillate from side to side and thus
convert rotary into linear motion in two directions.

The schematic Figure shows a cam groove 11 cut in a



1, lathe lead screw; 2, adjusting screws for gimbal ring;
3, clamping screws; 4, split bush; 5, projecting lugs for
bearings; 6, gimbal ring; 7, dowel pins; 8, roller;
9, slotted bar, fixed to lathe saddle; 10, cutting tool;
11, cam groove; 12, workpiece.

Under with the mechanism necessary to obtain this result.
The workpiece 12 can be held between lathe centres or in

the chuck, and cutting can proceed conventionally while the
saddle is oscillating from side to side. This oscillation is
produced by keeping the forward edge of the lathe saddle in
continuous contact with the sloping face of a metal gimbal
ring which rotates with the lead screw.

A bush 4 with projecting lugs 5 holds the gimbal ring 6
to the lead screw 1, both bush and gimbal ring being made
in halves so that they can be assembled around the lead screw.
Dowel pins 7 and holes are provided to facilitate correct
mating of the parts when the screws 3 are tightened on
assembly.

The slope of the gimbal ring can be set to move the
lathe saddle a predetermined distance by adjustment of the
two screws 2, and contact between the leading edge of the
lathe saddle and the face of the gimbal ring can be main-
tained either by a weight applied to the lathe saddle traversing
handle or by slight pressure on this handle. In order to
reduce friction at this point the forward edge of the lathe
saddle is provided with a projecting slotted bar 9 and a roller
8 which are fitted to the saddle in some convenient manner.

It will be understood that in order to cut a cam groove 11
as shown in the Figure, giving one oscillation per revolution,
the lathe gear train will be set to drive the lead screw at an
even ratio to the workpiece 12, but to produce two or more
oscillations per revolution the gear train would be set
accordingly.

In practice it has been found that the best procedure is
to apply a narrow cutting tool with maximum side relief 10
to the workpiece 12 in small cross cuts together with side
cuts, until the correct width and depth of slot are obtained.

I wish to express my thanks to Dr. R. C. Jordan for help
with the text and to Mr. D. H. Brown for making the
mechanism.

Switching by surface discharges

by J. S. T. LOOMS, B.Sc., A.Inst.P., Central Electricity Research Laboratories, Leatherhead, Surrey

MS. received 5th August 1960, in revised form 9th May 1961

Gaps for producing surface discharges, in the form of pairs of electrodes mounted on the surface of a dielectric in which a third electrode is embedded, have been used extensively as light sources (Tawil 1956, Schardin and Fünfer 1952). The application of a fast-rising pulse to the third electrode causes a discharge to bridge the surface between the pair, provided that a sufficient initial potential difference exists between them.

Such gaps may be used as switching elements, for which purpose they offer the following advantages over conventional two- and three-ball gaps and trigatrons:

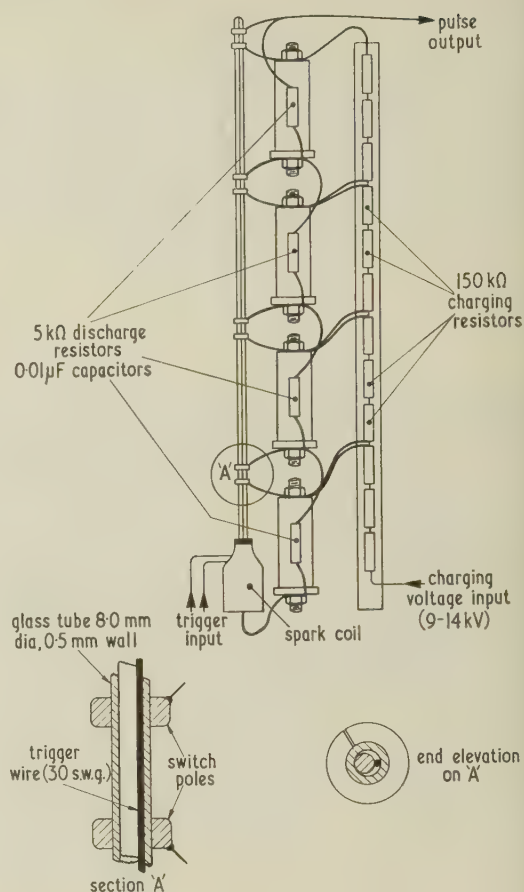
- The trigger-electrode is never connected to the pair; several circuits at widely different potentials can therefore be switched, either simultaneously or at controlled intervals, from the same trigger-pulse, the source of which is neither subject to damage by unwanted discharges from the switched circuits, nor loaded by them.
- A given gap fires over a wide range of voltage; in an impulse-generator using these gaps, variable output can be obtained without resetting the gaps; and simultaneous firing is obtained without the need for mutual irradiation of the gaps.

The action of the third electrode is discussed by Schardin and Fünfer (1952). The electrode appears to support a discharge which is advancing along the dielectric surface adjoining it, by drawing displacement current through the dielectric layer and thereby maintaining the current density in the discharge. Suitable dielectrics are therefore those in which high specific energy storage is possible, i.e. for which the product of permittivity and the square of electric strength is high, for example glass and mica.

One form of multiple-gap construction which has been found satisfactory uses a glass tube, sealed at one end and fitted with an internal wire as trigger-electrode, with external pairs of rings, adjustably clamped, as switch-poles. Surprisingly little surface damage has been observed on the glass; even plastics, such as epoxy resins and polyvinyl chloride, have been used in place of glass in temporary apparatus without early failure by carbonization.

A disadvantage of the switch is the size of pulse, of the order of kilovolts, which is required to fire it; since the load on the source of this pulse is small, however, it can usually be provided cheaply.

A compact impulse-generator, which uses surface discharge switching and is designed to operate in an enclosed screening-can, is shown in the Figure, together with details of the switch-construction. Using an ignition coil, as shown, the



generator can be fired with stage voltages between 9 and 14 kV without gap-resetting; this range can be extended where a source of larger firing-pulse is available.

The work described in this note forms part of the programme of research of the Central Electricity Research Laboratories, and is published by permission of the Director.

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Construction of a cadmium-lined box for neutron experiments

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Received 19th May 1961, in revised form 7th June 1961

studies of the behaviour of neutrons in various liquid media it is of importance to have the boundaries of the medium accurately defined. A convenient method is to use the boundary a continuous surface of a material which absorbs thermal neutrons very strongly, such as cadmium. Cadmium, however, has poor structural qualities: a large vessel constructed from it tends to distort unless the walls are made inconveniently thick. One possibility is to line a vessel with a cadmium sheet a vessel fabricated from a more rigid material, but it is normally very difficult to produce accurately flat surfaces in this way.

It was suggested by Mr. R. Bingle that it might be possible to produce a layer of cadmium bonded to a sheet of a more convenient structural material. The Industrial Metallurgy Department at this University has considerable experience in the bonding of dissimilar metals. Mr. K. J. B. McEwan of that Department devised a method of hot-rolling together suitably prepared slabs of cadmium, and a backing material. The bonding of cadmium to the most suitable backing is a function of commercial purity.

The initial thicknesses of the slabs were determined by the relative amounts of thinning anticipated in the rolling process. The thicknesses were of the order $\frac{1}{4}$ in. In our case, the final overall thickness of the plate is about $\frac{1}{8}$ in., with not less than 0.03 in. of this being cadmium. The essentials of the process are: (i) vapour degreasing followed by scratch-brushing; (ii) the plates to be heated to 250° C, and rolled at this temperature;

(iii) rolling to final thickness to be completed in one pass; (iv) flattening the bonded plate by roller-levelling. The bonding between the sheets is strong enough to permit normal manipulation—for example a sharp bend can be made without any difficulties arising.

The vessels were required to be of parallelepiped form, and a mechanically sound joint was required between the edges of the plates forming the sides of the box, which at the same time did not permit any neutrons to leak into the system. The solution adopted was to make up a cadmium-containing solder (i.e. 35% wt. cadmium, 65% wt. tin, melting point 180° C) and use this neutron absorbing solder to complete the sealing of the vessels. A small fillet of solder at the joints of the plates ensures a continuous cadmium surface within the vessel, and hence its non-transparency to thermal neutrons.

It is believed that the use of a cadmium-based solder for its neutron absorbing properties is novel, and that the application of this and the cadmium-aluminium bonded plates form a very convenient technique which may find various applications in neutron physics work.

We are most grateful to the staff of the Industrial Metallurgy Department at this University, and in particular to Mr. K. J. B. McEwan for giving us such ready co-operation in producing the bonded plates.

Notes and comments

Mesucora Congress

May 1961 the first Mesucora International Instruments Exhibition was held in Paris at the Centre National des Industries et des Techniques and simultaneously there was a Congress at the Salle d'Iéna.

This Congress was inaugurated by Professor A. Léauté of the Academy of Science and at the opening session representatives from Germany, United Kingdom, Switzerland and France read papers. At each of the succeeding sessions four or five eminent people from the countries mentioned above, plus also Denmark, Holland and Italy, gave technical papers covering a wide range of subjects under the general headings 'New elements in measurement instrumentation', 'Application of new measurement procedures', 'Measurement of physical characteristics of materials', 'Production quality control', 'Recording and data processing', 'Servo systems and their components', 'Regulation', 'Automation'.

At the afternoon session, when the writer was in the chair, the first speaker was M. J. Vastel, Compagnie Générale T.S.F.,

Paris, whose subject was 'Mass spectrometry as a procedure in industrial analysis'. He was followed by Dr. G. Klein, Philips, Eindhoven, who gave an interesting paper entitled 'Various aspects of the measurement of low voltages'.

The third speaker was Dr. J. Thomson, B.S.I.R.A. London, who, in his paper entitled 'New electronic elements in measurement instrumentation' introduced three of the recent major developments of the Research Association.

The final speaker was Professor Dr. H. Frieser, Technical High School, Munich, whose subject 'Photography as a means of measurement and store of information' proved extremely fascinating.

At all the sessions the attendance was good and there was effective simultaneous translation into French, German and English using the inductive loop system with personal selective transistorized receivers.

The Congress papers will be published in a book available from Association Mesucora, 37 Avenue de Breteuil, Paris 7, at the price of 50 N.F.

L. A. WOODHEAD

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep her informed of their new or improved products. The Institute of Physics and The Physical Society assumes no responsibility for the statements given below; information for these has been taken from literature supplied.

Point plotter. Bryans Aeroquip Ltd., 1 and 15 Willow Lane, Mitcham, Surrey.

The Bryans Point Plotter is a compact keyboard instrument designed to stand on a desk or bench and is primarily intended for use with the Bryans two coordinate plotting table, enabling the use of the latter for plotting the points of a graph when the coordinates of the points are available in numerical form. Alternatively, the point plotter may be used for any application when an operator has to produce a voltage proportional to a number.

The unit has a sloping top on which are mounted the X and Y numerical keys, each axis being provided with four decades of keys, and positive and negative keys to facilitate the plotting of graphs which appear in more than one quadrant. To the right of the keyboard is mounted the point bar, which lowers the pen on to the paper when the coordinates have been set up. At the top of the sloping front are the mains switch and pilot lamp, and under a cover are the scale factor controls which enable any number set up on the keys to be scaled to give full pen travel on the plotting table.

The unit, which is mains operated and consumes about 25 w, contains a double stabilized power supply for each of the two axes, each supply feeding into its appropriate attenuator. The attenuators are of the Kelvin-Varley type, and are built up with four decades of precision resistors, giving a maximum number of 9999 available on the keys of each axis. The output from each attenuator is taken into fine and coarse scale factor controls and thence to a 12-pin output plug. The stability of the power supplies is to about 0.1%, and the attenuators are also accurate to about 0.1%. This results in overall accuracy to about 0.2%, and repeatability to about 0.1% of full-scale.

Level indicator and controller. Thomas Industrial Automation Ltd., Station Buildings, Altrincham, Cheshire.

This instrument, known as the 'Levelator' gives not only a continuous indication of the contents of silos, tanks, hoppers etc. but it will also operate visual and audible alarms. The equipment uses one electrode only for both continuous measurement and control.

The electrode system can be of the rigid variety for small vessels and of the flexible type when the depth of the container exceeds 6 ft. The electrode head can be situated up to 150 ft from the control unit.

The long term stability and reliability of the equipment is said to be very high and it is unaffected by normal mains and temperature fluctuations.

Self-adhesive scales. Loughborough Glass Co. Ltd., Loughborough.

Made in transparent P.V.C. these scales are claimed to be resistant to water and a wide range of chemicals and to be

ideally suited for use on chemical plant and laboratory apparatus. They are easy to apply and remove and appearance and serviceability said to compare very well with more permanent graduations. Both upward and downward reading scales are available in centimetres (subdivided millimetres) and in inches (subdivided in 0.1 in.). They are supplied in 36-yard rolls, each with 72 complete scale sequences—either of 37 cm or of 1 ft. Upward scales are printed in black, downward in blue.

N.E.L. vacuum manometer. N.G.N. Electrical Ltd., Accrington, Lancs.

The new manometer developed at the National Engineering Laboratory is designed to reduce errors due to leakage of air into the closed limb. This leakage introduces errors in measurement which increase rapidly at higher pressure measurements. A bulb is blown at the top of the closed limb to provide expansion space for entrapped gas which arises either by leakage past the mercury column or evolution from the mercury itself. An identical bulb is blown at the bottom of the open limb to receive the mercury which falls from the other bulb when the manometer is connected to vacuum. In order to minimize the 'hammer' effect when the vacuum is suddenly released a short length of small bore capillary tube is used to connect the two limbs. The range covered is 0–300 mm Hg and it is claimed that the reduction in error compared to a conventional U-tube manometer with the same volume of entrapped gas is from 17 mm Hg error to 0.33 mm Hg error at 300 mm Hg.

Line fault locator. Ferranti Ltd., Edinburgh.

The fault locator is a new instrument designed to improve the practice of fault-finding on high-voltage transmission lines. It operates on the radar principle of pulse reflection, the reflection being caused by any fault which may be due to a flashover or to ice build-up on the line. The reflected pulses are received by the locator and displayed on a cathode ray tube for visual or automatic photographic record. The distance to the fault is found by measuring the time interval between the sending of the pulse and reception of its reflection. The locator has been designed for easy and simple operation in manned or unmanned sub-stations, and uses the normal station battery d.c. supply, making it independent of main voltage fluctuations.

A.C. microvoltmeter, type TF 1375. Marconi Instruments Ltd., St. Albans, Herts.

Covering the range 5 μ v to 15 v in twelve ranges, this instrument is portable and fully transistorized with self-contained battery supply. The frequency range is 50 c/s to 1 Mc/s with switch-selected low frequency rejection. Basically, the instrument consists of a frequency-compensated input attenuator with decade steps, and a seven-transistor frequency-compensated amplifier having a voltage gain of approximately 5000. Output from this amplifier is rectified in a full-wave bridge circuit before application to the meter; in addition, the output from the penultimate stage is available at a front-panel outlet. The 4 in. meter has an overload-protected movement with clear high-discrimination voltage

decibel scales. The instrument is intended to be used a variety of purposes; for example, as an oscilloscope amplifier, as a sensitive measuring-bridge detector, or field strength and aerial tests. In conjunction with a cable pick-up loop, measurement may be readily made of age flux emanating from mains transformers and electric wires. Input impedance and sensitivity are such that it can be used as a microammeter for detecting currents as low as 10^{-10} A.

Resistor phase meter. Dawe Instruments Ltd., London.

This is an instrument designed to measure the difference in phase angle between two signals in the audio or sub-audio frequency range. Both signal and reference channels feed current attenuators giving either low voltage sensitivity or a high input impedance or lower input impedance with increased voltage sensitivity. The attenuator outputs feed back to balancing circuits followed by amplifying and driving stages which drive bi-stable circuits. The outputs of the bi-stable circuits are differentiated and positive going pulses are derived which have the same phase relationship as the positive going excursions of the original input signals. Pulses arriving from one channel switch a further bi-stable circuit into its 'on' condition. Pulses from the other channel switch this bi-stable circuit to its 'off' condition. The mark-to-space ratio of the rectangular waveform thus formed is directly proportional to the phase difference of the input signals. The rectangular wave is integrated and a section proportional to its mean value obtained on a driving coil meter, the meter being directly calibrated in degrees phase over the range 0° – 360° . To prevent difficulty of interpretation when the signals are almost in phase, a 180° phase shift circuit may be selected and the 180° – 0° – 180° scale used. Frequency range is from 1 c/s–75 kc/s; there are three ranges of input voltage and impedance from 30–300 V to 10 M Ω down to 0.03 V–0.3 V into 10 k Ω . Phase accuracy is to $\pm 3^{\circ}$ at 10 c/s–10 kc/s, $\pm 5^{\circ}$ at 1 c/s–10 c/s and $\pm 10^{\circ}$ at 10 kc/s–20 kc/s. Power supplies can be mains or battery.

Mass spectrometers. Leland Instruments Ltd., Westminster, London, S.W.1.

Manufactured by the Compagnie Française Thomson-Houston, the TH.N.202 series, employing interchangeable permanent magnets, includes three models: the TH.N.202D, which is specifically designed for the separation of a pair of molecules of similar mass and is based on 'double collection'; the TH.N.202SD which features, in addition, an electronic scanning device allowing single collection spectrum recording and may be switched instantaneously to either single or double collection; the TH.N.202S, which features purely single collection and spectrum recording by electrostatic focusing. At any time the models 202S and 202D may be converted into the TH.N.202SD by the addition of elements and spaces provided. The interchangeable permanent magnets have fields of 835, 1560 and 3150 gauss cover the mass ranges 2 to 8, 8 to 32 and 30 to 100 respectively, and any other combination of magnets to cover mass ranges up to 100 can be supplied. Using double collection, the spectrometer may be used for precise measurements of isotopic ratios of gaseous or solid elements, for gas concentration measurements in binary mixtures, for deuterium measurements in H_2 , HD or D_2 , and for tritium in HT, T_2 and HT_2 , etc. Employing single collection the appropriate detector may be used for automatic continuous analysis of the

spectrum of one of the three mass ranges 2 to 8, 8 to 32 and 30 to 100 (and up to mass 150 on request), for automatic analysis of predetermined masses by high voltage switching and, if required, for the continuous and automatic recording of the concentrations of specified gases. Housed in a monobloc unit the spectrometers include two assemblies—the separator assembly comprising ion source, analyser tube, magnet, two target collector, pumping system, power supplies and safety devices; and the electronic measurement assembly comprising two linear amplifier chains, h.t. power supply and (in the S and SD models) a spectrum recorder, automatic spectrum scanner and, on request, automatic h.t. and sensitivity switching for measuring predetermined masses. These spectrometers are claimed to be capable of detecting a concentration of a specific isotope of as little as 0.1 part per million and have a resolving power of 50, which can be increased if required. Using double collection, for concentrations of less than 100 parts per million, the absolute accuracy of measurement is better than 0.1 parts per million, and for concentrations between 100 parts per million and 10000 parts per million the relative accuracy is to $\pm 0.1\%$. The instruments operate on a power supply of 220 V, single phase 50 c/s and consumption is 2.5 kW. For cooling purposes they require a water flow of 2 litres/min and in a day's use require 10 litres of liquid nitrogen.

Low resistance precision instrument switch. W. G. Pye and Co. Ltd., Granta Works, York Street, Cambridge.

This switch is designed for instruments which depend on the resistance of their circuitry and components for ultimate accuracy of measurement. The overall switch resistance is approximately 0.7 m Ω and the variation of the contact resistance is $\pm 20 \mu\Omega$. The overall resistance drift during the life of the switch is $\pm 50 \mu\Omega$. Thermal e.m.f. is 0.008 μ V/deg C with uniform change of temperature, and temperature gradient across the switch produces a maximum of 0.25 μ V/deg C.

The switch is totally enclosed and does not require maintenance of any kind. It is claimed that in life tests 20 million operations have been performed and the switch has remained well within the specification, showing, in fact, a slight improvement in the stability within the range.

Angle-beam transducers. Branson Instruments, Inc., Stamford, Conn., U.S.A.

This group of angle-beam transducers, for use with ultrasonic flaw detection equipment, has been designed primarily for the company's Sonoray flaw detector, but may also be used successfully with similar ultrasonic instruments. Angle-beam transducers often detect flaws undetected by the straight-beam type, they avoid multiple beam reflections in thin sections, they will more readily scan large areas, and they can be used where the shape of the component prevents direct contact with a straight-beam transducer.

Three types of angle-beam transducers are available, all of which incorporate high sensitivity crystals and a lucite wedge. The first type is the most versatile, because both transducer and wedge components are readily interchangeable; wedges to produce effective angles from 45° to 90° may be specified, and operating frequencies of 1, 2.25 and 5 Mc/s are available as standards. In the second type each transducer generates only one type of wave at only one angle, the wedge and crystal being fixed in position. The third type is a 'finger-tip' model, only $\frac{1}{4}$ in. square in crystal cross section and is designed for special applications where contact areas or access are limited.

Notes and comments

Notes on the Preparation of Papers for the *Journal of Scientific Instruments*

The following instructions refer to the main points which have to be considered in the preparation of a paper for publication, and authors offering papers to the *Journal of Scientific Instruments* for publication are asked to conform to these recommendations.

Manuscripts

Manuscripts should be typed in *double* spacing on paper not wider than 8 in. and not longer than 13 in. Only one side of the paper should be used, and a margin of 1-1½ in. should be left. As alterations in the text cannot be allowed once the paper is set up in type, authors should aim at absolute clarity of meaning and of typing, and should check the typescript carefully before submission. All manuscripts should be submitted in duplicate, and in addition to the fair copies, a set of small copies or prints of the diagrams (not larger than foolscap) must be attached to each MS. (This enables MSS. to be sent to two referees at the same time and so assists rapid publication.)

Abstract. An abstract is printed at the beginning of the paper immediately after the title, name(s) of author(s), and place of employment of author(s). Two extra copies of the 'title and abstract' page are required for the records.

Mathematics. It is not necessary to give detailed derivations of mathematical expressions and formulae in a published paper when the work is straightforward; it is quite sufficient to indicate the method of treatment and the final results.

References. In the text bibliographical references are made by giving the name of the author and the year of publication in brackets, e.g. (Jones 1942), and details are given in the last section, 'References', where the references are arranged in alphabetical order of authors' names and in date order for each author.

Drawings

Drawings should be in Indian ink on tracing cloth, tracing paper or white card, with lettering in soft or blue pencil; lettering of a size suitable for reduction will be inserted by our draughtsman. The drawings should in general be sufficiently large to allow of reduction in printing, and the lines should therefore be bold; the frame lines of graphs should be slightly finer than those of the plotted curves.

Full details are available in the Institute and Society's 'Notes for Authors', obtainable from the Editor and Deputy Secretary, The Institute of Physics and The Physical Society, 1 Lowther Gardens, Prince Consort Road, London S.W.7.

Papers for publication in the *Journal of Scientific Instruments* should be sent to the Editor and Deputy Secretary at the same address.

Letters to the Editor

We should like to draw readers' attention to the publication of Letters to the Editor in this journal. We have arranged

with our printers to publish letters received up to six weeks before the date of publication, provided they are reported upon favourably by our referees. For example, items for publication in the November issue of the journal should be received in the office not later than 20th September. Letters from the Continent will be published in French or German if necessary to avoid further delay. This also applies to the other two journals of The Institute of Physics and The Physical Society, i.e. the *Proceedings of the Physical Society* and the *British Journal of Applied Physics*.

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British Journal of Applied Physics

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NEW BOOKS SECTION

NOTES AND COMMENTS

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Instrument for the continuous determination of the mechanical internal energy losses in high-polymer solids over a wide range of temperature and frequency

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Abstract

An instrument has been developed for the continuous measurement of the dynamic modulus and the mechanical loss factor of high-polymer solids, over the frequency range 0.5 c/s to 2 kc/s, and at temperatures between -100°C to $+140^{\circ}\text{C}$. The phase and amplitude of torsional oscillation of an electromagnetically driven specimen are measured with the aid of a capacitance transducer. The temperature is controlled by an adiabatic vacuum system.

and from $\tan \delta$ and G' at particular high frequencies, defined by resonance of the specimen. The terminology is explained fully in the next section. The temperature is continuously variable, and can be held constant at any desired point. This, coupled with the fact that the specimen need never be disturbed, are important features of the apparatus. The ranges covered are from 0.5 c/s to 2 kc/s in frequency, and from -100°C to $+140^{\circ}\text{C}$ in temperature.

1. Introduction

In the two decades since the pioneering work of Alexandrov and Lazurkin (1940), the phenomenon of the variation of the moduli of high-polymer solids with temperature and frequency of stressing has received much attention. The associated mechanical energy losses have usually been investigated simultaneously (see, for example, Marvin, Fitzgerald and Ferry 1950, Schmieder and Wolf 1952, Thomas and Robinson 1955). The importance of these measurements lies in the fact that they can be interpreted in terms of the ultimate structure of the polymer.

A number of instruments have been used to assess the dynamic mechanical properties of polymers. These range in complexity from the simple torsion pendulum of Schmieder and Wolf (1952) to the twin-transducer system of Marvin, Fitzgerald and Ferry (1950). The actual measurements obtained, on some of these more complex instruments, usually required considerable algebraic manipulation (Smith, Ferry and Kemp 1949) before they are recognizable in terms of the mechanical properties of the specimen. The simpler methods, on the other hand, may demand approximation methods to obtain detailed information from the results (Thomas and Robinson 1955).

The authors have endeavoured to avoid these two extremes and the apparatus to be described yields the mechanical properties of the polymer directly. Further, the one apparatus yields results over a considerable range of temperature and frequency without readjustment of the specimen.

The apparatus was constructed to examine the effect of chemical and physical structure on the dynamic characteristics of high-polymer solids. Eventually it is hoped to use it to perform the inverse function, of deriving structural information from the dynamic characteristics.

The dynamic characteristics are obtained from measurements of $\tan \delta$ and G^* over a continuous frequency range,

2. Theory of dynamic measurements

Forced vibrations

A cylindrical specimen of the polymer is rigidly clamped at its lower end and oscillated torsionally at the other by an auxiliary coil. The coil is excited in sinusoidal torsional oscillations by the application of an alternating voltage. The equation of motion for this driven system is

$$I\ddot{\theta} + kG^*\theta = Q_0 \exp(i\omega t) \quad (1)$$

where $Q_0 \exp(i\omega t)$ is the sinusoidal torque experienced by the coil, with ω representing the angular frequency and t the time; I is the moment of inertia of the vibrating system, which in this case can be identified with the moment of inertia of the coil, as the inertia of the specimen is small in comparison; θ is the angular displacement of the coil and k a constant dependent upon the specimen dimensions. For a cylindrical specimen $k = \pi a^4/2l$, where l is the length of the cylinder, and a the radius. G^* is the complex dynamic shear modulus. Solution of Eqn (1) gives

$$\theta = \frac{Q_0 \exp\{i(\omega t - \beta)\}}{\{(kG' - I\omega^2)^2 + k^2G''^2\}^{1/2}} \quad (2)$$

where

$$\tan \beta = kG''/(kG' - I\omega^2). \quad (3)$$

G' (the storage modulus) is defined as the stress in phase with the strain/strain and G'' (the loss modulus) as the stress in quadrature with the strain/strain. Then the complex modulus (Ferry, Sawyer and Ashworth 1947), $G^* = G' + iG''$, and the ratio $G''/G' = \tan \delta$, the loss tangent. Any pair of the terms G^* , G' , G'' or $\tan \delta$ defines, completely, the mechanical state of the system.

There are three distinct regions of frequency measurement, according to the relative magnitudes of kG' and $I\omega^2$.

(a) *Inertia forces negligible.* At low frequencies $kG' \gg I\omega^2$, and the inertia terms in Eqns (2) and (3) can be neglected. In Eqn (3), when this condition holds, $\tan \beta = G''/G' = \tan \delta$, and measurement of $\tan \beta$ gives the value of $\tan \delta$ directly.

† Now at The Chemistry Department, Victoria University of Manchester.

Again in Eqn (2), considering peak values only, $Q_0/\theta_0 = kG^*$, and G^* is determined. The mechanical properties in this frequency region, extending from 0.5 c/s to approximately 200 c/s, are thus simply determined as G^* and $\tan \delta$.

(b) *Inertia forces not negligible.* When $kG' \approx I\omega^2$, account must be taken of the term $I\omega^2$, if this is no longer negligible. This situation occurs when the test frequency becomes greater than one-sixth of the resonant frequency. The values of G' and G'' can be found by substituting the known values of I and ω into the solutions of the simultaneous quadratic equations (2) and (3).

$$\text{Thus } G' = \frac{1}{k} \left(\frac{Q_0}{\theta_0} \cos \beta + I\omega^2 \right) \quad (4)$$

$$G'' = \frac{1}{k} \left(\frac{Q_0}{\theta_0} \sin \beta \right). \quad (5)$$

(c) *Resonance.* On raising the frequency, the system will eventually pass through an amplitude resonance. If the resonance curve of θ against ω is fairly sharp (i.e. G'' small) then $I\omega_R^2 = kG'$ and G' is determined. Also frequencies ω_1 and ω_2 can be found at which the amplitude of vibration has dropped to $1/\sqrt{2}$ of the resonance value ω_R . Then $\tan \delta = (\omega_2 - \omega_1)/\omega_R$, and the mechanical properties at the resonant frequency are accurately determined.

3. The apparatus

The apparatus is shown diagrammatically in Fig. 3 and can be seen in the photograph (Fig. 2) and in Fig. 1.

The specimen, a cylinder of 0.22 cm diameter and length approximately 1 cm, is clamped rigidly at its lower end and

vibrated torsionally at its upper end. A rectangular coil is firmly fixed to the top of the specimen. The vibrations are excited by passing an alternating current through the coil which is situated in the field of a strong permanent magnet

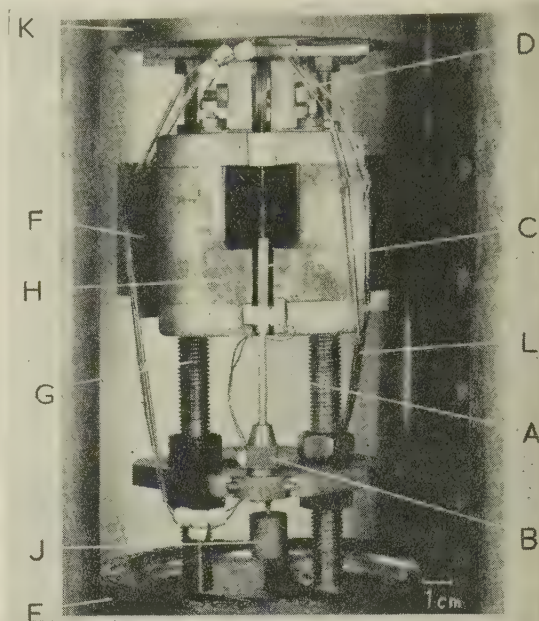


Fig. 2. Cross-sectional view of the apparatus.

The attachment between specimen and coil is made by allowing a cooled specimen to expand while wedged into a hole in the coil (see Fig. 3).

The permanent magnet is sandwiched between two brass plates clamped by nuts on threaded brass rods. These rods support the apparatus by means of nuts resting on two washers embedded in a rubber bung. The holes so formed in the bung are closed by two smaller rubber bungs. The two supporting rods pass through the plates clamping the magnet and screw into the ends of two thicker threaded brass rods. A lower platform is formed by another brass plate, supported between pairs of nuts on the large threaded rods. It is on this platform that the pin vice for holding specimens is clamped. The pin vice is held in position in a hole through the platform by two screws set at 120° to each other. These permit a limited amount of lateral adjustment to the bottom of the specimen.

The angular displacement of the coil is detected as a lateral displacement of two aluminium vanes, which project symmetrically from the lower end of the coil. Each vane is adjacent to, and parallel with, a small insulated brass plate. Insulation is achieved by cementing the plates to the magnet with a thermally setting epoxy resin. Rotation of the coil varies the separation of the vanes from the plates and results in a change in capacitance, which is sensed by a 'capacitance meter' (Attree 1955) and converted into a voltage proportional to the displacement. After appropriate calibration the amplitude and phase of the output voltage from the capacitance meter yield the absolute amplitude and absolute phase of the coil displacement.

The small rectangular coil itself was constructed by winding fine enamelled copper wire on a brass former of H-shape cross section, until the wire in the hollow lay flush with the metal. The end of the wire, to be earthed, is kept in contact with the brass former by the pressure of the other winding

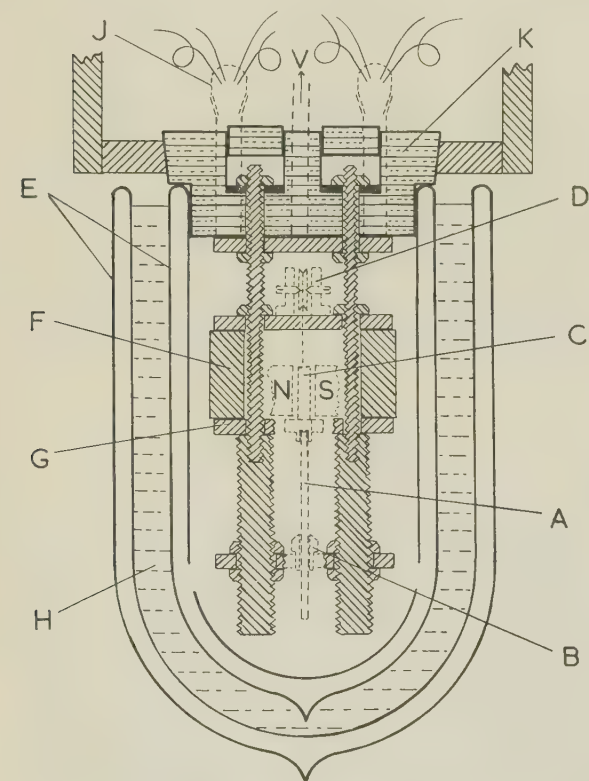


Fig. 1. Instrument for the continuous measurement of the mechanical internal energy losses in high-polymer solids.

other end of the coil is secured to the top of the former out electrical contact and led loosely to the leads from oscillator. The vibrating system is suspended from the point of the upper end of the former by fine uninsulated wire, which passes over a pulley to a counterbalancing weight (approximately 20 g). This counterbalances the weight of the vibrating system and in addition maintains it in tension. The suspension wire causes the end of the coil and the vanes to be earthed through the pulley supports.

Temperature control

The temperature of the specimen can be varied between 0°C and $+140^{\circ}\text{C}$ by an adiabatic vacuum technique, a form of which has been used by Robinson (1955). The whole of the vibrating system, including the permanent magnet is enclosed in a modified Dewar vessel thus thermally isolated, apart from conduction through air. The Dewar vessel has a hole in its inner wall so that fills the annular space. Conduction through the air prevents heat exchange to occur between the apparatus and a liquid temperature bath (liquid nitrogen or heated silicone oil) placed outside the Dewar vessel. When it is desired to maintain the instrument at constant temperature, the modified Dewar vessel is evacuated to a pressure of 10^{-1} mm Hg . This pressure is sufficient to considerably reduce heat exchange through the gas and bring air damping down to an extremely low level (Berry and Nowick 1958).

A cross-sectional view of the apparatus inside the Dewar vessel is shown in Fig. 1. Great care has been exercised to minimize heat losses by conduction. The brass rods supporting the vibrating system end in a large rubber bung, which fits into the mouth of the Dewar vessel. There is a hole in the side of the bung to prevent its suction into the vessel under reduced pressure. The leads from the thermocouples pass through glass seals and are made from copper, where possible, to reduce thermal conductivity. Their diameters are also kept to a minimum.

With these precautions it was found possible to hold the temperature stable to within $\pm 1^{\circ}\text{C}$ quite easily and, by previous manipulation of the temperature baths, to well within $\pm 0.5^{\circ}\text{C}$. The temperature was measured by using thermocouples, one in contact with the top of the magnet, the other with the bottom support of the specimen; the thermocouple e.m.f.s were measured on a vernier potentiometer, and calibrated against temperature by the use of standardized standard temperature baths.

The transducers

That part of the apparatus, which enables the motion of the vibrating system to be followed, is termed the transducer. In the present apparatus it comprises two parallel plate capacitors connected in parallel (see Fig. 3). One plate of each capacitor is formed by one of two aluminium vanes attached to the coil.

The vanes rotate with the coil and hence change the capacitance of both capacitors simultaneously, and in the same sense (i.e. capacitance is increased or decreased in both). The change in capacitance, which is proportional to the linear displacement of the vanes, is converted into a proportional d.c. voltage (Attree 1955) by the capacitance meter. The value of a dual capacitor system is that the sensitivity of detection is doubled and the vibrating system is made isometrical. Difficulty arises, however, in calibrating the output voltage in terms of the absolute displacement of the vanes if the two capacitors are not identical in value. Assume the two capacitors C_1 and C_2 are equal (this can be realized

in practice). Let us examine the effect of the identical motion of one plate of each capacitor system,

$$\text{total capacitance } C = 2P/d \quad (6)$$

where d is the separation of the plates, in this case about 0.01 cm , and P is a constant determined by the effective area of the capacitor plates, approximately 0.1 cm^2 .

A small angular displacement produces a small change in the separation of the capacitor plates of average value δd (about 0.0001 cm) and a corresponding small change in capacitance δC .

Then from Eqn (6)

$$\delta C = -\frac{2P}{d^2}\delta d \quad (7)$$

The change in capacitance is thus proportional to the vanes' displacements, if these are small. It has been demonstrated by Attree (1955) and the authors, that the output voltage from the capacitance meter varies linearly with the change in capacitance detected, that is

$$\delta V = k\delta C \quad (8)$$

where δV is the measured output voltage from the capacitance meter, and k is some constant.

$$\text{Hence} \quad \delta V = -\frac{2P}{d^2}k\delta d \quad (9)$$

The change in the output voltage δV is proportional to the displacement δd . The absolute value of δV depends on the value of d itself. When δV is calibrated in terms of the absolute angular displacement of the coil, some measure of the value of d must also be taken into account. The value of d determines the capacitance C , and it is this which is measured, rather than d itself. In parallel with the two detecting capacitors is therefore connected an adjustable capacitor C_3 which comprises two concentric cylinders, the inner one earthed and the outer one live. The capacitance can be varied by the movement of the inner cylinder in an axial direction. The movement is derived from a micrometer screw gauge. Differences in the screw gauge readings are therefore proportional to absolute changes in capacitance. The capacitance meter is used only with a certain definite value of the capacitance on the input side. When this critical value pertains, a galvanometer in the circuitry registers zero, and the meter is termed 'in balance'. This is the normal working condition with C_1 , C_2 and C_3 all in circuit, C_1 and C_2 can be switched out of circuit in turn, and C_3 adjusted until the meter is restored to the 'balanced' condition. The amount by which C_3 has to be adjusted in each case gives a measure of C_1 and C_2 . The application of this arrangement will be dealt with in § 4.

The mechanical construction of the transducer had to be very precise, because of the fine tolerances involved. In order to attain maximum rigidity, the vanes were made from a solid block of aluminium. Appropriate machining was carried out to leave a hollow cube, open at one end, and having two vanes projecting symmetrically from a pair of diagonally opposite corners. The coil's cross section, is the same as the square aperture in the transducer, and the end of the coil was wedged firmly into this opening. The joint was made secure by bonding with Araldite F, but electrical contact is maintained between the former of the coil and the vanes. The transducer vanes and the coil are now a rigid system. The vanes forming the moving plates of the two capacitors are earthed via the coil former and the suspension

wire. The stationary plates are flat rectangular pieces of brass, each identical in area. These two plates were bonded to the poles of the permanent magnet, so that, when the coil is suspended in its working position, each aluminium vane lies adjacent and parallel to one of the identical brass faces. The Araldite which bonds the plates to the magnet also serves as an effective insulation from earth. Contact from the 'live' connection of the capacitance meter to the plates is made through fine enamelled copper wires. The effective areas of the plates of C_1 and C_2 were made the same by having identical raised rectangular sections on each vane, facing the stationary plates. These raised portions are smaller in size than the stationary plates, and can always be adjusted to lie completely within the perimeter of the latter. It was mentioned previously that the specimen is fixed into a circular hole in the vibrating system. This hole of diameter 0.21 cm, and depth 0.2 cm, lies in the under side of the transducer, and thus vibrates with the coil.

The circuit

The block diagram (Fig. 3) shows the general arrangement of the electronic apparatus. A variable frequency oscillator

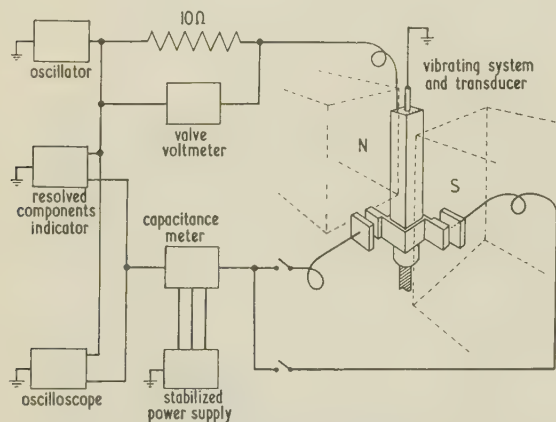


Fig. 3. Block diagram showing the general arrangement of the electronic apparatus.

supplies an alternating voltage (0.5 v maximum) to the coil, via a 10 Ω resistor. The voltage drop across the resistor is measured with a valve voltmeter (by Brüel and Kjaer) and provides a useful monitoring of the current (0.01 A maximum). For frequencies above 25 c/s, a Solartron type C.O. 546 oscillator is used in conjunction with a Solartron type V.P. 250 resolved components indicator. At frequencies lower than this a Solartron decade oscillator, type O.S. 103, is used in conjunction with the low-frequency resolved components indicator, type V.P. 253.

The 'live' sides of the transducer (the brass plates) are led off through separate plug and socket connections to the capacitance meter. The principle of this meter (Attree 1955) is that the small changes in capacitance, produced by the oscillation of the coil, frequency modulate a Franklin oscillator, which drives a nonode, frequency-modulated discriminator. The net effect is thus the production of a voltage response proportional to the changes in capacitance on the input side. In the present case, as the capacitance varies sinusoidally, the output is a sine wave of the same frequency as the frequency of oscillation, and with amplitude proportional to the coil displacement. When the input capacitance

has a value which gives the Franklin oscillator a nominal frequency of 465 kc/s, the meter circuit is 'in balance', and a galvanometer is arranged to register zero current to indicate this. Attree's original paper should be consulted for further details.

The output signal from the capacitance meter is fed into a resolved components indicator, which measures the amplitude of its components, in phase and in quadrature with the oscillator output, i.e. effectively the phase and amplitude of the signal are measured. A double-beam oscilloscope (Cossor, model 1049) is used to monitor the signals from the oscillator and from the 'capacitance meter'. By this method it is ensured that the signals measured are distortion-free sine waves, of low noise level. Great care is taken to ensure proper earthing of the appropriate terminals and mechanical parts of the apparatus, as the signal-to-noise ratio is found to be very sensitive to poor earthing.

4. Calibration

Two quantities are required to be measured by this instrument, the loss tangent $\tan \delta$ and the complex dynamic modulus G^* . One experimental measurement is of phase lag β between input voltage to the coil and output voltage from the capacitance meter. The other measurements are of the r.m.s. value i of the driving current passing through the coil and the r.m.s. value v of the output voltage of the capacitance meter. Calibration must therefore be performed to allow $\tan \delta$ to be found from $\tan \beta$ and complex modulus from i and v .

Mechanical internal energy losses in carbon steel are very low at normal and low temperatures. Measurement of $\tan \delta$ with steel wires as specimens, thus determines the phase shift occurring in the apparatus (termed 'background' $\tan \delta$). Determinations at resonance revealed that the $\tan \delta$ values for the steel wires were in the region of 0.004, this relatively high value was probably due to losses occurring in clamping of the wires. Measurements of $\tan \beta$ were made over the complete frequency range and at different temperatures with some ten different wires (including some copper and Eureka). A satisfactory 'background' calibration of $\tan \delta$ for the instruments was thus achieved. All measurements were in good agreement, with a maximum experimental scatter of 0.005. The background calibration curve for $\tan \delta$ is shown in Fig. 4.

The calibration of the torque applied by the coil for given values of the current was a relatively easy matter. Using fine steel wire, of known rigidity modulus, the angular

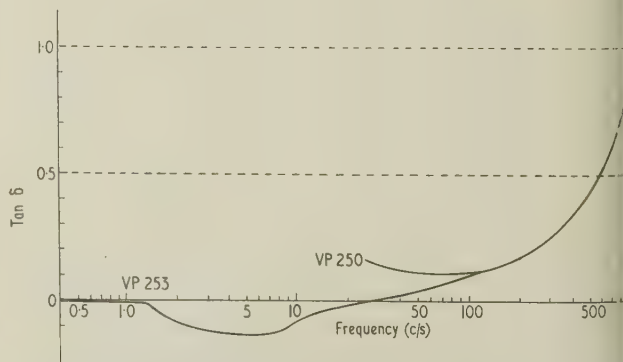


Fig. 4. Background calibration curve for the loss tangent ($\tan \delta$) over a complete frequency range, using types VP 253 and VP 250 resolved components indicators.

tion of the coil was measured by a light-spot technique. The total optical path used was in the region of 300 cm, but, so, only deflections occurring at large values of the current produced measurable deflections. The amplitudes of the r.m.s. currents at various frequencies agreed exactly with the static deflections, and the torque was found to be directly linear with current. The value of the torque was 0.01 dyn cm per ma (r.m.s.).

The most difficult calibration was that of determining the strain amplitude from the output voltage of the capacitance transducer. The sensitivity of the detection varies with the separation of the plates (i.e. the capacitance). The sensitivity (expressed as volts per radian deflection) should be proportional to the square of the capacitance of the transducer (Eqn (9)).

$$\delta v / \delta \theta = -KC^2 \quad (10)$$

where K is a constant incorporating all the constant terms. A large number of sensitivity determinations at different frequencies of the capacitance of the transducer verified this formula. The angle of deflection was measured by a light-spot technique. The capacitance was measured in the arbitrary units of a micrometer driven coaxial capacitor, which was connected in parallel with the transducer in the electronic circuit. A value of the coaxial capacitance equivalent to the transducer could be found by switching the capacitor out of circuit and adjusting the coaxial capacitor. A condition of equivalence was judged by the centre-zero microammeter, which indicated correct tuning when unswitched.

The value of K in Eqn (10) was found to be $0.230 \text{ d}^{-1} \text{ capacitance}^{-2}$. In any experiment once C was measured the value of the angular deflection could be calculated from Eqn (10).

The weakness in this procedure was the instability of the electronic circuits. Over the relatively long periods of time necessary for measurement, the balance of the capacitor bridge circuit often varied sufficiently to invalidate the reference setting for capacitance values. It would be better to use some independent means of measuring the capacitance of the transducer.

5. Measurements

The specimen and vibrating system are mounted symmetrically with respect to the pole-pieces of the magnet between the stationary transducer plates. The separation of the transducer plates is arranged to be as small as possible, thus giving maximum sensitivity. The values of the capacitors C_1 and C_2 are detected separately, but are generally made the same so that the simple relation (10) can be employed.

The temperature is usually varied from low to high, and the initial step is to create the low temperature with a liquid nitrogen bath. Thereafter, the temperature is allowed to rise in stages, with the temperature bath, partially or completely, removed. The rigidity of the specimen is high at low temperatures, and low at elevated temperatures. To obtain the maximum possible amplitude (still very small), at low temperatures, the specimen is made fairly long (~ 2 cm). At elevated temperatures, however, the rigidity of normal polymers is so reduced that the resonant frequency of the specimen tends to shift to frequencies even lower than 100 c/s. To counteract this the specimen is made as short as

possible (3 mm). The length of the specimen can be easily varied by raising or lowering the lower brass platform and allowing the specimen to slide through the hollow pin vice.

6. Discussion

The merits of the instrument lie in the wide ranges of temperature and frequency, over which continuous measurement is possible. Another advantage is that the maximum strain amplitudes are only of the order 10^{-4} . At these low strains there is a probability that results will be strain independent, although this fact must be verified with each polymer. The sensitivity of this capacitance transducer is quite as good as that obtainable by inductive and photoelectric techniques. An inductive transducer, however, would load the system to a greater extent than the capacitance device and would be liable to pick up stray signals from the adjacent driving coil. Photoelectric techniques present practical difficulties when applied over wide temperature ranges (Robinson 1955). The other possibility of piezoelectric detection was immediately dismissed because it is temperature-sensitive and mechanically loads the system.

The accuracy of the determinations of the dynamic modulus and loss factor demands some comment. The dynamic modulus can always be determined to an accuracy of better than $\pm 5\%$. The accuracy of the measurement of the loss factor $\tan \delta$ is better than $\pm 1\%$ at high values of $\tan \delta$, but falls to $\pm 20\%$ in the region of $\tan \delta = 10^{-2}$.

It is expected that modifications of the present apparatus will considerably extend the ranges covered, and improve the accuracy. The upper limit in frequency is imposed by the resonance of the system, and it is not expected that this will be raised significantly. There is no reason, however, why the lower frequency range should not be extended by several powers of ten. It is expected that the temperature range will also be improved considerably by modifications in the mechanical construction.

The instrument is being used successfully in both academic investigations of high polymers and in the commercial testing of plastics. Detailed results of this work will be reported subsequently (Lord and Wetton 1961, Wetton and Lord 1961).

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Digitizer-to-tape punch-coupling unit

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Abstract

The unit briefly stores the output (twelve binary digits) from an optical or mechanical digitizer and produces signals which will cause a high-speed five-track tape punch to punch the stored information in four rows of holes. Three rows contain the twelve binary digits from the digitizer, while the fourth contains a marker hole and information set on four key switches. Except for the seven valves necessary to drive the tape punch and digitizer light source, the unit uses transistors as its active circuit elements.

1. Introduction

THE electronic digital computer with its capacity for high-speed repetitive calculation is the ideal machine for processing experimental data. While it is possible to transfer data to the computer input medium by hand, there are two important advantages in doing this automatically. In the first place human error is eliminated and, in the second, more data can be handled so that new methods of treating them become practicable. Methods of direct analogue to digital conversion exist (Susskind 1958, Winterbottom and Walters 1961) and are appropriate to some situations. Many workers, however, already have experimental set-ups where the data are recorded by a potentiometric recorder; they only wish to have a copy of the data in digital form. This may be simply achieved by fitting a mechanical or optical digitizer to the recorder and then converting its output to the input medium of the computer.

Many single-turn mechanical and optical digitizers (Tiffany 1957) have a twelve binary digit ('bit') output; that is to say, the position of the moving part of the digitizer is defined by the pattern of closure of twelve switches or the illumination of twelve photocells. However, teleprinter tape, which is used as the input and output medium of some digital computers, has only five tracks and, if the output of the digitizer is to be transferred to this medium, it must be stored and then punched out at not more than five bits at a time. The unit to be described does this and, in addition, enables a limited amount of other information to be inserted between the digitized numbers.

2. The output pattern

A digitizer with a twelve-bit output is able to represent up to 4096 distinct positions of its shaft, though, for reasons connected with coding, it is common practice to make only 1000 positions available when each decimal digit is represented by four bits.

In computer terms, 'code' is used to mean the way in which the bits of a character (i.e. one row of five bits across the tape) represent a decimal digit, while 'pattern' may be used to describe a group of characters which are always repeated in

the same order. As computers can be programmed to accept input data in almost any pattern and code,* the pattern to be planned to satisfy other criteria. The one adopted is easy to read (see Fig. 1) and simple to decode for plotting (Molyneux and Schneider 1960) or checking purposes. Each

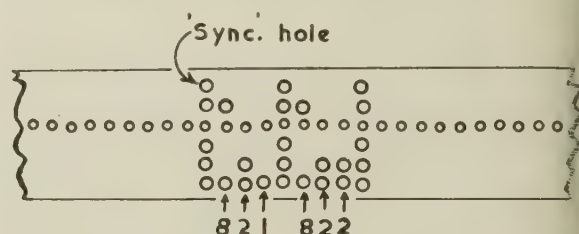


Fig. 1. Paper tape punched with two numbers in the output pattern (Watts reflected decimal code).

the decimal digits is represented by the bits, which occupy the four lower tracks. The top track is used to indicate the start of a number and the hole in this track is called a 'synchronizing hole'. Though it would be possible to punch a number from the digitizer in three characters, the author has found it desirable to include a fourth character called the 'starting character'. This character immediately precedes the hundreds character and contains the synchronizing hole. The other four bits of this character are controlled by the setting of key switches and may be used to carry additional information relevant to the digitized data.

3. Block diagram (Fig. 2)

The rate at which numbers are digitized is determined by the repetition rate of a clock-pulse generator (see Section 4). Each clock-pulse triggers a delay circuit, which produces an output about seven milliseconds later. The output from the delay circuit drives a commutator. This consists of two sets of two units and four coincidence circuits, and produces a negative pulse in each of four lines in turn. The pulse length is equal to the time between clock pulses, though the instant of changeover from one position to the next occurs 7 milliseconds after the clock-pulse.

Four of the output amplifiers (which are connected to the output valves and hence to the punch selector solenoids) are each fed by four gate circuits. These four channels are concerned with punching either the decimal digits of the output number or the four optional bits of the starting character. The gates are operated (or 'opened') by pulses in the commutator.

* G. C. Midgley has written sub-routines which enable the Ferranti 'Pegasus' computer to read and punch numbers in the required pattern. The routines for Watts 'reflected decimal' and Elliot 'datex' code are available for both 'machine orders' and 'auto-code, Mk. 4'.

r lines (labelled 1st, 2nd, 3rd, 4th, Fig. 2), hence, the character punched out when a pulse occurs in a particular mutator line is determined by the state of whatever is connected to the gate. Twelve of the gates are connected to memory circuits', which store the output from the digitizer. The connections are such that the bits representing the hundreds digit are stored by the circuits connected to the

4. Operation

Broad outline

The timing of punching a complete number and starting character is complicated, and it is best to describe the sequence and then to relate it to the action of the punch. First, the memory circuits are cleared by sending a positive pulse to the

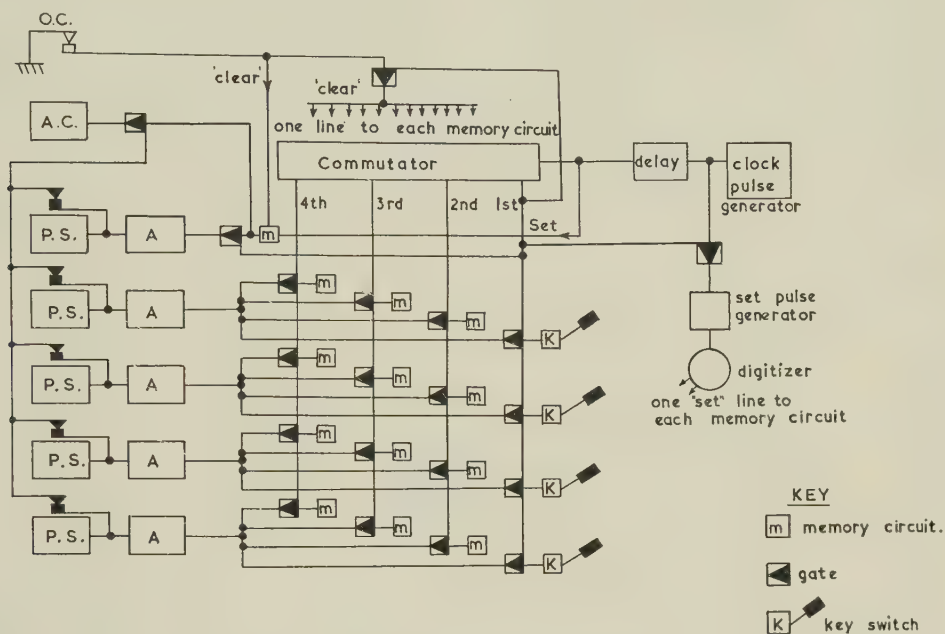


Fig. 2. Block diagram. A.C., 'actuate' solenoid; P.S., punch selector solenoid; O.C., operation complete circuit; A, output amplifier.

es operated by the 2nd commutator lines, while the tens
1 units information is controlled by the 3rd and 4th lines
pectively. The 1st commutator line operates five gates,
ur of which are connected to key switches, while the fifth

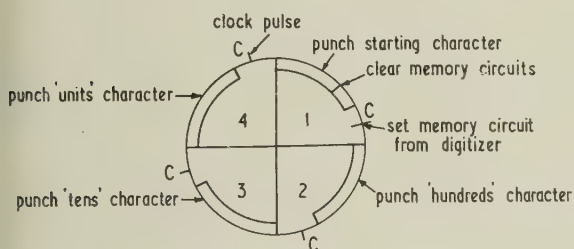


Fig. 2(a). Commutator timing.

connected to a permanent memory circuit which always contains a 'hole' signal.

The memory circuits (see Fig. 3) are bistable pairs. Either TR1 conducts (the 'clear' state) or TR2 conducts (the 'set' state). If the circuit is connected to an output amplifier (a gate transistor) while it is in the second state, a hole can be punched corresponding to the binary digit '1', but if it is in the other state (TR1 conducting) it is clear and no hole is punched corresponding to the binary digit '0'. Likewise, key switches have two positions corresponding to the binary digits '1' and '0'. The permanent memory circuit always contains a '1'.

common emitter circuit via the left-hand diode in each of the memory circuits (see Fig. 3). Then the memory circuits are set by sending negative pulses to the same point via the right-hand diode. Not all the memory circuits are set, only those which correspond to the digits representing '1' from the output of the digitizer at the time of the setting pulse, and the memory circuits then contain the twelve bit number which represents the position of the digitizer shaft. After punching the starting character the next three characters representing the hundreds, tens and units digits of the output number are punched and the cycle is complete.

The punching sequence

The punch selector solenoids are each fitted with a pair of contacts, which open only when the selector mechanism is in position. The circuit is arranged so that the 'actuate' solenoid which controls the punching mechanism is energized only when the state of these contacts agrees with the setting of the output amplifiers. This prevents the punching of wrong characters caused by the sticking of the solenoids or failure of the output valves.

When the punching action is complete, a pair of contacts on the punch mechanism close. This 'operation complete' circuit is used for two purposes. Firstly, every time the punch is operated, it clears the 'permanent' memory circuit controlling the 'actuate' solenoid and so brings the punch to rest. This 'permanent' memory circuit is set to '1' by every clock pulse, so that a character is punched shortly after each clock pulse. The 'operation complete' circuit is also used

to clear the twelve memory circuits associated with the digitizer, although this action is controlled through a gate which is open only in the first position of the commutator.

The ultimate limit to the number of characters which can be punched in a second is set by the punch mechanism, and with the authors' punch (Model 25 high-speed reperforator

ever, apart from the synchronizing hole, the bits of the character punched at this time (the starting character) are determined by the settings of the key switches so that the state of the memory circuits is immaterial. As soon as the punch selector solenoids have taken up their correct positions the 'actuate' solenoid is energized and the character punched

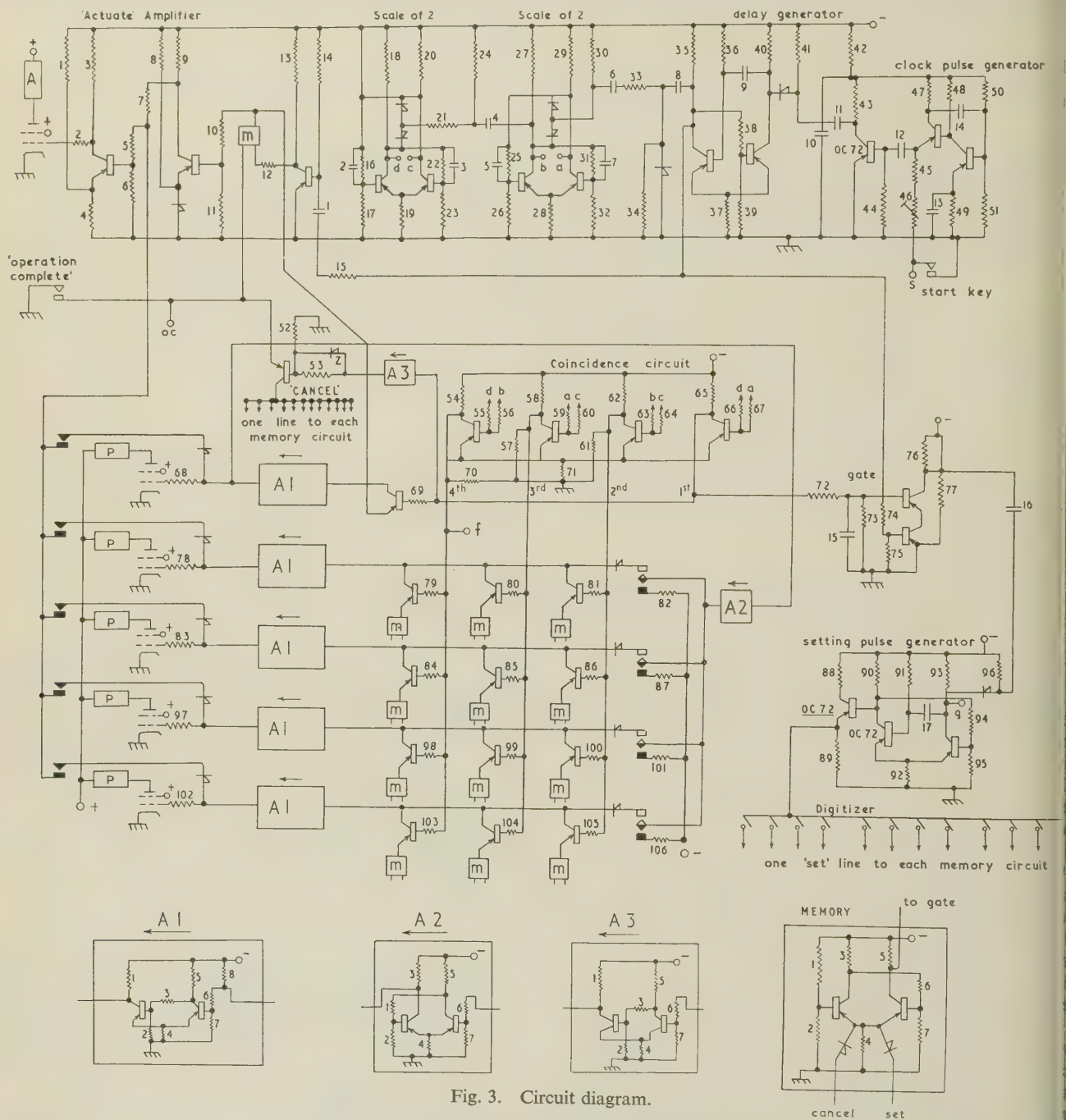


Fig. 3. Circuit diagram.

by Messrs. Creed Ltd.) is limited to about 24 characters. However, the checking procedure reduces the maximum rate to about 20 characters per second or five complete digitized numbers.

The cycle of storing and punching a number starts when the commutator moves into the first position. At this moment the memory circuits associated with the digitizer are holding the bits of the previous number (Fig. 2(a)). How-

When the punching action is complete, all the memory circuit are cleared. The gate controlling the 'setting' pulse is also open, so that when the next clock-pulse occurs (the commutator does not change until 7 milliseconds later) the memory circuits are set from the digitizer. The new number now punched out, four bits at a time, in each of the next three positions of the commutator, thus completing the cycle.

5. Circuit diagram (Fig. 3)

though the individual circuits are original in the sense they have been devised from first principles, there is a vast literature on transistor circuits and it is unlikely similar circuits have not been used and described. The unit of the circuit design will therefore be limited to the connection of its various parts.

The punch selector solenoids are normally not energized, the grids of their driving valves are held at about -18 v the associated transistor circuit (A1, Fig. 3). To energize selector solenoid the input to its driving circuit (A1) must be made less negative than about 7 volts. The inputs to these units are normally held more negative than this by the current flowing through a $6.8\text{ k}\Omega$ resistor (R82 for example),

connected to an amplifier pair, which has a similar function to the output amplifiers (A1) although its output may be inhibited at the junction of R5 and R7. The 'permanent' memory circuit (which controls the 'actuate' solenoid) is set by each clock pulse and, if no signal is passed to any of the output amplifiers, the 'actuate' solenoid is energized by the output from the pair. Suppose, however, that an 'operate' signal is passed to one of the output amplifiers (A1) then the junction of R5 and R7 will be maintained at about -2 v preventing the operation of the 'actuate' solenoid. When the selector solenoid is in position, the contacts carrying the inhibiting signal open and the output pair can then energize the 'actuate' solenoid. This inhibiting circuit prevents the punching of wrong characters caused by the failure of the

Resistors (ohms)

1. 4.7 k	20. 8.2 k
2. 47 k	21. 10 k
3. 18 k	22. 82 k
4. 470	23. 56 k
5. 120 k	24. 39 k
6. 120 k	25. 82 k
7. 120 k	26. 56 k
8. 15 k	27. 8.2 k
9. 8.2 k	28. 470
10. 27 k	29. 8.2 k
11. 39 k	30. 39 k
12. 2.2 k	31. 82 k
13. 6.8 k	32. 56 k
14. 56 k	33. 10 k
15. 15 k	34. 10 k
16. 82 k	35. 6.8 k
17. 56 k	36. 180 k
18. 8.2 k	37. 560
19. 470	38. 220 k

39. 150 k
40. 6.8 k
41. 150 k
42. 1.8 k
43. 3.3 k
44. 10 k
45. 150 k
46. 1 M
47. 470
48. 10 k
49. 15 k
50. 68 k
51. 82 k
52. 6.8 k
53. 27 k
54. 10 k
55. 150 k
56. 150 k

57. 10 k
58. 10 k
59. 150 k
60. 150 k
61. 10 k
62. 10 k
63. 150 k
64. 10 k
65. 10 k
66. 150 k
67. 150 k
68. 47 k
69. 39 k
70. 10 k
71. 470
72. 82 k
73. 22 k
74. 82 k

75. 22 k
76. 10 k
77. 10 k
78. 47 k
79. 39 k
80. 39 k
81. 39 k
82. 6.8 k
83. 47 k
84. 39 k
85. 39 k
86. 39 k
87. 6.8 k
88. 47
89. 1 k
90. 2.7 k
91. 82 k
92. 220

93. 8.2 k
94. 270 k
95. 82 k
96. 120 k
97. 47 k
98. 39 k
99. 39 k
100. 39 k
101. 6.8 k
102. 47 k
103. 39 k
104. 39 k
105. 39 k
106. 6.8 k

Capacitors (μF)

1. 0.05
2. 0.01
3. 0.01
4. 0.01
5. 0.01
6. 0.002
7. 0.01
8. 0.002
9. 0.06
10. 100
11. 0.002
12. 1
13. 100
14. 0.1
15. 0.01
16. 0.01
17. 0.1

Transistors (ohms)

A1	A2	A3	Memory
6.8 k	56 k	82 k	82 k
100 k	22 k	47 k	12 k
82 k	27 k	270 k	15 k
1 k	220	220	1 k
6.8 k	1.8 k	8.2 k	6.8 k
12 k	56 k	10 k	56 k
8.2 k	22 k	1.5 k	100 k
6.8 k			

3 Transistors (marked) are type OC72
All others are type OC71
All diodes are type OA81
All valves are type EL84

Mullard Ltd.

Power supplies
Transistor circuit
Screens of valves
Anodes of valves

18 v (5%) at 120 mA
180 v (5%)
150 v (5%)

se resistors are connected to the collectors of the gate resistors so that a selector solenoid only operates if more than about 2 mA passes through the resistor.

The memory circuits are said to be 'set' when TR2 is conducting and 'clear' when TR1 is conducting. The emitter of a transistor is connected to the collector of TR2 and unless memory is 'set' its emitter will be at about 18 volts.

A gate transistor (p-n-p type) does not conduct unless its base is more negative than its emitter, which can only occur in the memory circuit to which it is connected is 'set', and an appropriate commutator line is negative. When these events occur together the gate transistor conducts and energizes (by means of the output valve) the punch selector solenoid.

For simplicity the block diagram (Fig. 2) shows each key switch connected to the output amplifiers through a gate, but in fact it is more economical to have one gate feeding the input to all the switches. As the information conveyed by the key switches is used during the punching of the synchronizing hole, as this hole is the only information ever punched in the track, the key switches can share the gate used to control the track. It is then only necessary to have an amplifier (Fig. 3) with sufficient output to drive the load connected to the key switches (four $6.8\text{ k}\Omega$ resistors connected in parallel). This amplifier takes its input from the output of the fifth channel.

The valve which energizes the 'actuate' solenoid is con-

output valves or by the sticking of the selector solenoids. It also ensures that the 'actuate' solenoid is operated at the moment that the selector solenoids are exactly in position.

When a character has been punched, the 'operation complete' contacts close and clear the permanent memory, which in turn releases (via the output pair) the 'actuate' solenoid and so brings the punch to rest. In the first position of the commutator these contacts are also used to clear all the memory circuits associated with the digitizer. This clearing action takes place through the gate driven by A2.

6. Optical digitizers

While the circuit may be used as it stands with most mechanical digitizers, additional circuits are needed when it is to be used with an optical digitizer. The nature of the additional circuits depends on the characteristics of digitizer and the circuit given, though typical, is particularly intended for a type made in this country (type FD24 by Hilger and Watts Ltd.).

Two additions are necessary to the basic circuit. Firstly, the output from the setting pulse generator must be matched to the neon light source of the digitizer; secondly, an amplifier must be interposed between each photocell and its associated memory circuit. The circuit is shown in Fig. 4.

A pulse of $1\text{ }\mu\text{A}$ at the input of the amplifier will 'set' the memory circuits. Each neon lamp receives a pulse of 8 mA lasting for about 5 milliseconds.

7. An addition to the basic circuit

When the basic circuit is used, numbers are punched at a rate determined by the clock-pulse generator. Its repetition rate, therefore, determines the time coordinate of the digitized numbers. The generator shown in the circuit diagram (Fig. 3) is intended for trial runs, and, with the circuit to be described, is used for 'single-shot' working. It does not have a precise repetition rate.

One usually requires the values of a dependent variable (represented by the digitized numbers) to be recorded at equal increments of its independent variable so that the clock-pulses should occur at equal increments of the latter. If the independent variable is changed at a rate determined by the mains frequency (by a synchronous motor for instance), then the

clock-pulse rate should bear some definite relationship to mains frequency. This can be done electronically using well known divider circuits, although other means may be more convenient. The authors have used a synchronous clock motor with a vane attached to its shaft, which interrupts a light falling on a photocell. The output of the photocell is then amplified and used as a clock-pulse.

However, where an independent variable is changed in discrete steps it is convenient to be able to record a complete number for each, and in this case a 'single-shot' facility is useful.

Single-shot working (Fig. 5)

In this mode of operation the clock-pulse generator is controlled by an additional memory circuit, which is 'set'

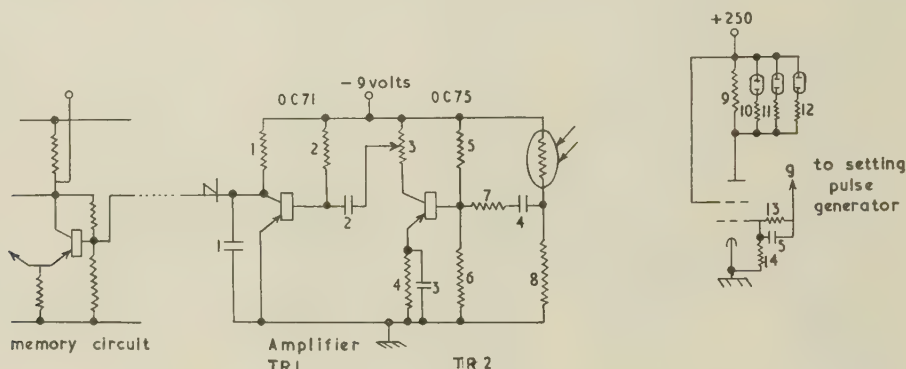


Fig. 4. Additional circuits necessary for an optical digitizer.

Resistors (ohms)		Capacitors (μ F)
1. 18 k	8. 180 k	1. 0.05
2. 470	9. 18 k	2. 0.25
3. 5 k	10. 12 k	3. 0.25
4. 4.7 k	11. 12 k	4. 0.25
5. 68 k	12. 12 k	5. 0.25
6. 22 k	13. 2.2 M	
7. 15 k	14. 1 M	

Transistors TR1 OC71 TR2 OC75 } Mullard Ltd.

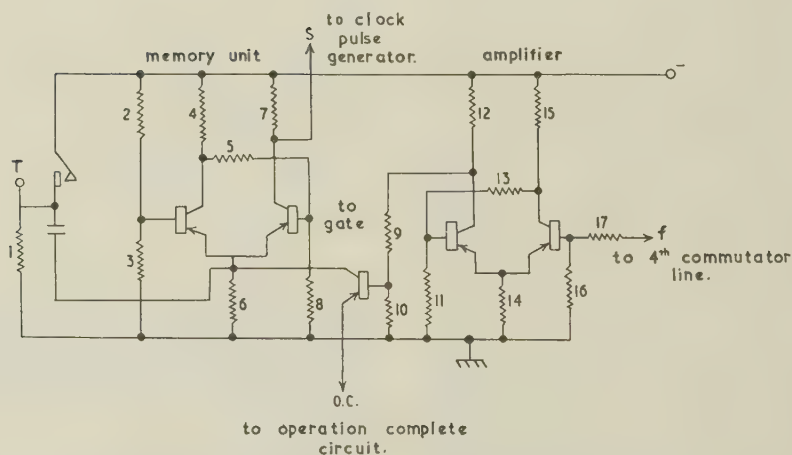


Fig. 5. Additional circuit for single-shot working. (A complete number is punched whenever the switch is closed.)

Resistors (ohms)		Capacitor
1. 22 k	10. 6.8 k	0.01 μ F
2. 82 k	11. 47 k	
3. 12 k	12. 8.2 k	
4. 15 k	13. 270 k	
5. 56 k	14. 220	
6. 1 k	15. 8.2 k	
7. 6.8 k	16. 2.7 k	
8. 100 k	17. 10 k	
9. 27 k		

ternal trigger pulse and cleared automatically just after units' character has been punched. Suppose the memory controlling the clock-pulse generator has just been cleared; when it is clear, the clock-pulse generator is prevented from running and nothing further happens until the memory circuit is reset. When it is reset by the external trigger pulse, the device punches out the four characters of a new number and then comes to rest. Provided the interval between the trigger pulses is longer than the time necessary to punch four characters (i.e. less than about five character pulses per second) a number is recorded each time a character pulse occurs.

8. Applications

The applications of the device are numerous but it is worth mentioning the work that the two units are engaged on at the present time.

One unit (fed by an optical digitizer and working in the continuous mode) is fitted to a commercial recording spectrophotometer (type CF4 by Optica Ltd. (U.K.)) and is being used to analyse and synthesize complex absorption curves. It is shortly to be used (with the digitizer fitted to a standard photometric recorder) for similar work on electron spin resonance spectra. The other unit (fed by a mechanical digitizer and working in the single-shot mode) is being used to record the results of an experiment (under the direction of T. A. Littlewood) in which infra-red wavelengths in the 1 to 3μ region are measured with respect to a standard krypton line.

9. Reliability

The two units have now been in use for about a year and have themselves given no trouble, though some faults have been caused by the digitizers. One pattern of mechanical digitizer has given very good results while a mechanical and optical digitizer of another pattern have both caused faults, though in this case the optical digitizer has been the more satisfactory device. The reliability of the units themselves is a direct result of using transistors (instead of electro-mechanical devices) for storage and organization.

Acknowledgments

The authors gratefully acknowledge the assistance of G. C. Midgley (Department of Philosophy) and the staff of the Durham University Computing Laboratory in all matters concerning the computer. One of us (L.M.) would also like to acknowledge a most informative discussion on the problems of handling data in digital form with F. A. Johnson of the Royal Radar Establishment, Malvern.

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Notes and comments

Congress 1963

The second congress of the International Federation of Automatic Control (IFAC) will be held in Basle, Switzerland, in September 1963, at the invitation of the Swiss Association for Automatic Control. A committee of the British Conference on Automation and Computation will co-ordinate the submission of papers from the United Kingdom to the congress.

Most of the papers will deal with the theory or application of automatic control; a number will deal with the components and control devices. Subjects to be covered are as follows: Theory: discrete systems, stochastic systems, optimal systems, control systems, systems reliability; Applications: process control, computers, computer studies of applications (on or off line), digitalizing or adaptive control applications; Components: sensors and effective devices, measurement of the reliability of components.

Papers may be submitted in English, Russian, French or German. The final version of any paper by a United Kingdom author should be in the hands of the BCAC Committee not later than 1st June 1962.

Lists of papers from the United Kingdom should be sent to the Honorary Secretary, BCAC, c/o The Institution of Electrical Engineers, Savoy Place, W.C.2. General enquiries concerning the congress arrangements should be sent to the Secretary of IFAC, Dr.-Ing. G. Ruppel, Prinzregenten-Strasse, 79, Dusseldorf, Germany.

British Standard B.S. 3369: 1961

A new British Standard has been prepared relating to unified miniature parallel screw threads from 1.40 mm down to 0.30 mm diameter, having the 60° ISO/Unified basic form of thread. It is B.S. 3369: 1961. It may be obtained from the British Standards Institution, 2 Park Street, London, W.1.

New scientific monographs

Elek Books have started a new series of scientific monographs bearing the imprint Logos Press. The consultant editor is Professor Sir Harrie Massey and the executive editor is Dr. A. P. Willmore.

The Wave-guide Mode Theory of Wave Propagation by Dr. K. G. Budden will be the first monograph to appear in this new series. The book deals with the mathematical theory of two problems: the propagation of radio waves to great distances over the surface of the earth and the propagation of sound waves to great distance under water. The book will be of interest to graduate students of physics, mathematics and communication engineering, particularly those concerned with the use of low frequency radio waves for communication and navigational aids, to meteorologists concerned with electrical noise, and to acoustical engineers and others interested in underwater sound.

This book will be published in October by Logos Press, Scientific Publications (Elek Books Limited), 14 Great James Street, London, W.C.4.

Crystal-pulling furnace for gallium arsenide

by R. WICKHAM,* Services Electronics Research Laboratory, Baldock, Herts.

Abstract

The design and operation of equipment for pulling single crystals of gallium arsenide are described. Features of the design include a demountable quartz system with rapidity of set-up and ease of operation, close control of the arsenic pressure in the tube, and very good vision during the crystal growing cycle. The heating element is of resistance heated graphite and is traversable.

Introduction

FOR semiconductor work preparation of the material in the form of single crystals with the crystal lattice distorted as little as possible is necessary. A well-known method for growing single crystals from a melt whereby a seed crystal is placed in contact with the melt and then rotated and slowly drawn through a negative temperature gradient has been described by Czochralski (1918). Gallium arsenide however decomposes on melting, with the formation of the arsenic as a volatile component, and this makes it necessary to grow crystals under a pressure of arsenic in order to maintain stoichiometry. The general problem of processing compounds in which one of the components is appreciably volatile has been described by Boomgard, Kroger and Vink (1955), and Boomgard and Schol (1957) have shown that the dissociation pressure of arsenic over gallium arsenide at the melting point is 0.9 atmosphere. Consequently apparatus for growing gallium arsenide is normally designed to incorporate a temperature-controlled arsenic reservoir which provides this pressure, and this reservoir must be the lowest temperature point of the enclosure confining the vapour (approximately 600° C). Moreover the high reactivity of the arsenic vapour restricts the materials that can be used in the construction of apparatus to quartz and carbon, and the pressure involved requires that precaution should be taken for the safety of the operator.

The Czochralski technique is therefore difficult to modify for gallium arsenide since both the pulling and the rotation of the seed crystal must be carried out within a heated enclosure of quartz. To overcome the problem Gremmelmeir (1958) has described an apparatus in which a magnetic arrangement is used, whilst Richards (1957) has reported the use of a liquid gallium seal. In both cases induction heating was used.

Design considerations

Experience at Services Electronics Research Laboratory with the crystal growing of silicon (Marshall and Wickham 1958) and the floating zone refining of gallium arsenide (Cunnell and Wickham 1960) has shown that the features to be considered in the design of a crystal pulling furnace for gallium arsenide should be as follows: (i) a demountable quartz work tube to contain the gallium arsenide and the

arsenic vapour, (ii) a temperature-controlled arsenic reservoir maintaining a constant arsenic pressure of about 0.9 atm, (iii) accurate control of the crucible temperature within ± 1 deg C in the region of 1240° C, (iv) good visibility, (v) a minimum of vibration at the melt, (vi) safety and comfort of the operator.

A demountable quartz work tube which can be repeatedly reduced substantially the time required to mount the apparatus. The work tube may be sealed at its lower end to form a crucible for the melt, and closed at the top by a quartz plug which holds the seed crystal fitting accurately the bore of the tube, yet able to slide and rotate freely. A viewing arm taken to a remote point of the system can be used as a temperature-controlled reservoir.

It is impossible to prepare a sliding and rotating quartz 'lock' capable of making a perfect seal, and some arsenic loss must therefore be tolerated. For a lock of given dimensions the rate of arsenic loss can be reduced by making the external gas pressure greater than the arsenic pressure. This permits the loss of arsenic by diffusion only, but introduces convection and conduction heat losses. This arrangement is chosen for the operation of the equipment although vacuum operation could be used provided extra arsenic is used. In any case arrangements must be made to condense the arsenic vapour escaping from the lock in its solid form. Provision has to be made in the equipment for evacuating the work tube and its immediate surroundings before closing the lock and then establishing the background gas pressure. It is also essential to protect the operator from arsenic vapour in the event of the work tube breaking during operation, and from the radiated heat and intense light from the molten charge. It is convenient therefore to mount the work tube in a water-cooled metal box capable of withstanding both an excess internal gas pressure and vacuum. The box should be provided with a large door giving access for easy assembly and removal of the work tube and a large quartz window giving good visibility. There are two methods of heating the charge that can be employed, induction heating and resistance heating. Resistance heating is preferred because it is simple and reliable, can be flexibly used as desired, and its power units are simple and easy to control. Further, its high thermal capacity causes an inherent lag so that temperature upsets can be corrected before becoming very serious.

Vibration at the melt can best be avoided by mounting a high-speed rotating gear necessary for pulling and rotating the seed crystal independently from the furnace.

Mechanical design

The general arrangement of the furnace is shown in Figs 1 and 2. The chamber is fabricated by argon arc welding of 1 in. precision rolled plate of 3 to 5% magnesium aluminium alloy to B.S.S. 1477/N.P. 5/6 supplied by Messrs James Booth and Co. Ltd., Birmingham, as M.G.5. Grooves for water cooling are cut externally in the chamber and covered with plates on which water manifolds are fitted.

* Now at Admiralty Engineering Laboratory, West Drayton, Middlesex.

box has its own cooling system which is arranged so all O-rings and seals are adequately cooled. There are water supplies to the heater electrodes and framed viewing windows.

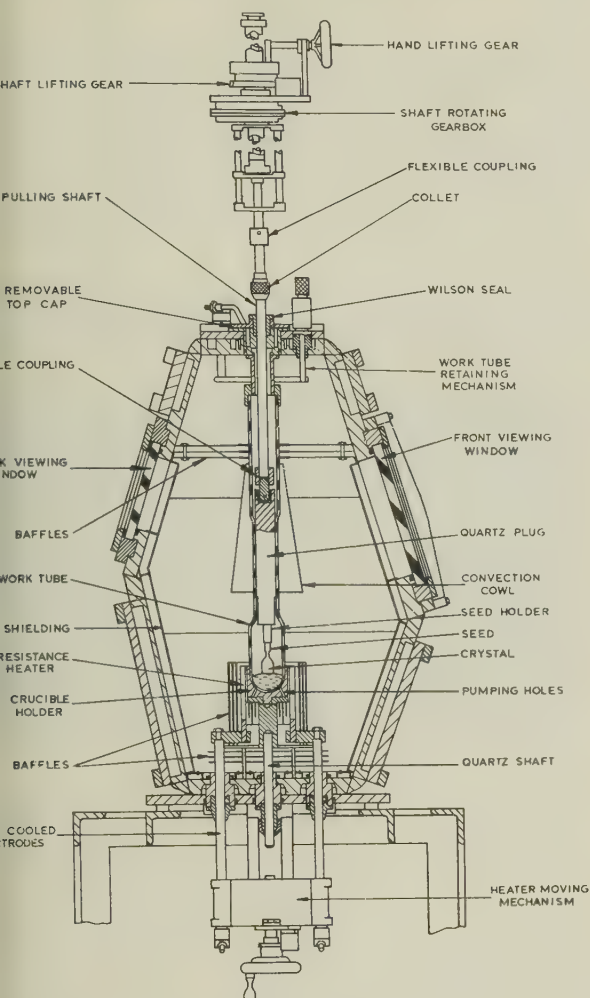


Fig. 1. Part sectional side view of furnace.

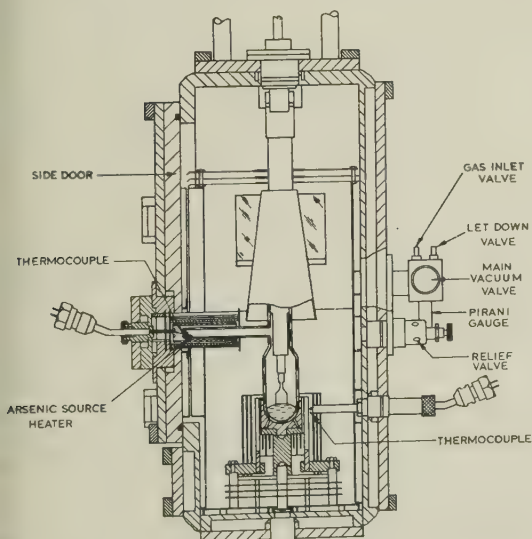


Fig. 2. Part sectional front view of furnace.

To avoid condensation troubles within the chamber when open to atmosphere the water is pumped from a static tank which is at room temperature. The inside of the furnace is divided into two sections by a set of three convection baffles near the top. The lower section in which the heater assembly is housed has the water-cooled internal faces covered with shielding to minimize losses from convection, whilst the top section where arsenic condensation is encouraged has the faces left uncovered.

The work tube consists of four separate pieces of quartz were fused together. The lower piece is used as the crucible and is expendable. The middle section is a piece of tubing of smaller bore which has first been shrunk on to a specially prepared molybdenum mandrel and then lapped and polished with diamond abrasive compound. The concentricity and diameter of the bore does not vary by more than 0.0001 in. Joined to the side of this at right angles is a side arm for the arsenic source which has a re-entrant formed at its end to house a thermocouple. The fourth and top section is a piece of tubing with a bore slightly larger than the shrunk section.

The lower end of the work tube is held in a graphite holder supported by a quartz rod which in turn is held in a Wilson seal. Around this is a heater which consists of a hollow graphite cylinder cut lengthwise at intervals around the circumference in order to present a high resistance path to the heating circuit. This is attached by lugs to the water-cooled copper electrodes which pass through Wilson seals at the bottom of the furnace, where they are attached to a sliding mechanism which can be operated either by motor or hand. Raising and lowering of the heater gives added flexibility in operating the furnace.

The supply to the heater taken from the mains is varied by two Variac transformers. The larger Variac changes the bulk of the supply, via a 230/50 v step-down transformer capable of delivering 300 A at 50 v. The smaller Variac, operated by a proportional d.c. motor, supplies a 230/5 v step-down transformer, the secondary of which is in series with the secondary of the 230/50 v transformer to supply the heater. The voltage of the heater (resistance $\frac{1}{2} \Omega$) is rectified and compared with a neon-stabilized reference voltage—any differences are amplified and fed to a proportional motor controlling the small Variac, thereby correcting the supply. Any small changes required in power can be made by varying the reference voltage. A diagram of the heating circuit is shown in Fig. 3.

A platinum/platinum-rhodium thermocouple is placed in an alumina protective tube as close as possible to the top of

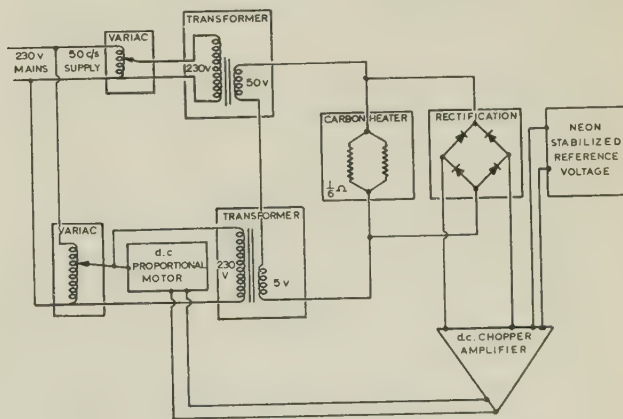


Fig. 3. Controlled voltage heater supply.

the heater. The temperature measured at this point is used purely as a reference for the operation and not for a control. From a temperature recorder the operator can observe the rate of change he is applying and by knowing the thermal time constant of the furnace he can determine when the full effect of the change has been made.

The heater has a baffle assembly around it to make it as efficient as possible.

The side arm is independently heated by a removable platinum wire heater wound on a cylindrical quartz former mounted on the side door of the furnace. This heater is baffled in order to minimize the heating effect from the main heater and is provided with its own thermocouple.

The power delivered to this heater is controlled by a temperature regulator so that the temperature of the thermocouple junction is maintained at 605° C independently of the main heater. A small quantity of arsenic (about 1 g) is placed in the end of the side arm. The pressure of the arsenic vapour will be determined by the temperature of this reservoir provided the work tube up to the lock is always at a higher temperature.

The upper end of the work tube extends into the top section of the furnace, which has been made deliberately much colder than the lower section. Any arsenic vapour escaping through the lock is confined within this top quartz section and condensed on the tube walls.

The work tube is held in a vertical position by a ground quartz plug entered into its upper end. The plug is itself lapped and polished so that its diameter is 0.001 in. smaller than the shrunk portion of the work tube. At its lower end a hole is bored to take a further tube in which the seed crystal is fitted by a quartz pin. A further hole drilled about $\frac{7}{8}$ in. up to join this hole makes it possible for the work tube to be evacuated when the plug is only just entered into the shrunk portion. A stainless-steel rod is joined to the upper end of the plug by a flexible coupling, this rod passing up through a removable water-cooled cap which is sealed into the top of the furnace by an O-ring. To maintain good thermal contact between the crucible end of the work tube and the graphite cap and also to resist the action of rotation and vertical movement of the plug a removable lever system is fitted which can be adjusted externally. To assist in maintaining the work tube at a temperature in excess of 600° C a cowl of carbonized nickel is fitted to take advantage of the hot convecting gas from the main heater. A detachable transparent quartz window 9 in. $\times$ 6 in. $\times$ $\frac{3}{8}$ in. thick, in a water-cooled frame is sealed to the sloping front by means of a large O-ring. This window ensures very good vision during the crystal-growing cycle. A similar smaller viewing window 6 in. $\times$ 6 in. $\times$ $\frac{3}{8}$ in. thick is fitted for further observation from the back.

Speedy access to the inside of the furnace for removal and replacement of work tube, heater, etc., is made through a large water-cooled door on the side of the furnace sealed by a large O-ring held by wing nuts.

The independent rotation of the seed crystal and the vertical movement of the stainless-steel pulling rod are achieved by variable speed servo-motors (Velodynes).

A d.c. motor is fitted for the heater traversal mechanism suitably geared down. To reduce vibration at the melt to a minimum this high-speed rotating gear is mounted on the independently supported control and power unit chassis which is immediately adjacent to the chamber. Rotation of the slow-speed worm and wormwheel assemblies on the chamber is imparted by shafts with flexible couplings. The movement of the pulling rod is achieved by a pair of spring-

loaded half nuts working in a square-threaded hollow shaft. To permit raising and lowering by the hand wheel these half nuts can be quickly disengaged by turning a cam plate at the top.

Operation

A square section rod of gallium arsenide is cut from a polycrystalline ingot such that there is a piece of single crystal at one end. A small hole is bored ultrasonically through the rod about $\frac{1}{4}$ in. from the other end. This together with approximately 100 g of gallium arsenide in the work tube have their surface contamination removed by etching in a mixture of four parts by volume of hydrochloric acid and one part of nitric acid and are then washed in de-ionized water.

The cleaned gallium arsenide is loaded into the crucible end of the work tube and approximately one gram of arsenic is put into the end of the side arm. The seed crystal is attached to the quartz plug by a quartz pin and the plug inserted into the lock portion of the work tube. The top cap of the furnace is removed and work tube assembly inserted into the open hole via the open side door. The crucible end of the work tube is lowered into the graphite cup and the top cap threaded over the pulling rod and clamped to the top of the box by four knurled screws. The pulling rod, which has previously been attached to the quartz plug, is then fixed to the pulling and rotating mechanism by means of a coupling which is made flexible to allow for any slight misalignment. The retaining lever mechanism is left a little slack on the side of the work tube to allow for expansion during the heating cycle. The side door is then closed and sealed and the side arm heater threaded over the side arm and sealed to the door.

The quartz plug is withdrawn so that the evacuation hole drilled in the bottom of the plug is exposed at the top of the lock thereby putting the work tube into direct communication with the chamber. The whole is then evacuated to a residual air pressure of 2.5×10^{-3} mm Hg during which the gallium arsenide and arsenic are outgassed at approximately 300° C. The lock is closed by lowering the plug about 2 in. and the oxygen-free nitrogen introduced to the chamber at a pressure of one atmosphere.

It is essential at all times during the heating cycle to ensure that the lock temperature is higher than that of the arsenic source. This is accomplished at the outset by raising the graphite heater by the hand wheel to the highest position possible. Power is delivered to this heater and the side arm heater so that the temperature of the arsenic source and the lock are approximately 450° C and 800° C respectively. The gallium arsenide charge during this period will probably have risen to a temperature of about 1000° C. A period of 20 minutes with 4 kw on the main heater and 40 w on the side arm heater has been found satisfactory.

The main heating power is then raised to 6.3 kw and the arsenic source set to 605° C. The heater is slowly lowered by motor to the melting position. This has been found to be where the crucible end of the work tube is in the middle of the heater. When the charge is fully molten the main heater is further lowered so that the charge is in the top half of the heater. The reference thermocouple can then be inserted and the seed crystal lowered into the melt after the temperature has stabilized. The liquid meniscus around the seed informs the operator whether the seed is sufficiently wet to start growing operations.

In order to grow, the lift rate is started at $\frac{1}{2}$ cm/h and the temperature set to fall slowly, the rate of fall being seen on the temperature recorder. When the crystal has grown

wards to the optimum diameter the pull rate is increased to 1 cm/h. With an occasional drop in temperature to compensate for the fall of the level of the liquid, the crystal can be made to maintain constant diameter. With experience, all the gallium arsenide in the hemispherical crucible end of the work tube can be successfully moved enabling the crucible end to be used repeatedly. After operation the heater system is cooled in the reverse order to the warming procedure. The grown crystal is removed by withdrawing the quartz tube from the work tube. The work tube is ready for use again after cleaning in aqua regia.

Conclusions

The equipment enables crystal pulling of gallium arsenide to be conducted in an accurately controlled arsenic atmosphere. In consequence of this, turbulence in the melt is

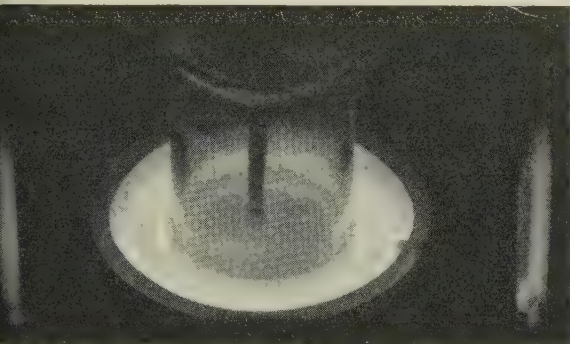


Fig. 4. View of growing crystal.

negligible. The rate of arsenic loss is tolerable (approx. 500 mg) during the operation. Crystals have been grown within the limits of 2.8 cm diameter 5 cm long and 1.2 cm diameter 12 cm long. A detailed study on these crystals is now in progress and will be the subject of another report.

With the aid of a water cell with darkened glass there has been no discomfort to the operator from either radiated heat or intense light and excellent visibility is obtainable at all times through the quartz viewing windows. The view presented to the operator from the front window is shown in Fig. 4 and shows the quality of the visibility.

Acknowledgments

The author wishes to acknowledge his indebtedness to Mr. K. H. J. C. Marshall for the pulling of the crystals and the design of the controlled voltage heater supply circuit, to Mr. R. Keys for the manufacture of the precise quartz locks, to Mr. C. H. Beaumont for helpful suggestions, and for the fabrication of the quartz work tubes and to Dr. O. Simpson for reading the manuscript. The author also wishes to make acknowledgment to the Admiralty for permission to publish this paper.

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Method of linearizing thermistor thermometer data in calorimetry

by H. V. LARSON, M.S., I. T. MYERS, M.S., Ph.D., and W. H. LE BLANC, B.S., General Electric Company, Richland, Washington, U.S.A.

MS. received 24th April 1961

Abstract

A method of correcting for the non-linearity of thermistor thermometers in calorimetry is described. The correction may either be experimentally determined, or calculated from the thermistor specifications. This system of reducing thermistor data was applied to measurements over temperature differences of several degrees in two different adiabatic calorimeters. A linear temperature resolution of 10^5 to 1 was easily obtainable.

Introduction

Thermistor thermometry has many advantages. The sensitivity of the average thermistor is about ten times that of a platinum resistance thermometer. Also, the small size reduces the mounting problems as well as the total heat capacity and thermal lag of a calorimetric system. When medium or high resistance thermistors are used, the lead resistance becomes small compared with the thermometer resistance, and it is often possible to dispense completely with four-lead resistance measuring techniques, with their consequent inconvenience.

The non-linear characteristic of the thermistor, however, limits its usefulness (Anderson 1958, Atkins and Settingington 1959). If a small temperature interval is used, the thermistor is linear, but measurement accuracy is curtailed. It is often desirable to use larger temperature intervals, with the consequent increase in accuracy. This paper describes a method of removing the effect of thermistor non-linearity from the final experimental results, even though the temperature range is large.

General principle of the method

The rate of temperature rise in an adiabatically operated calorimeter is given by $P = CdT/dt$ where P is the power input to the calorimeter and C is its heat capacity. When resistance thermometers are used, dR/dt is measured rather than dT/dt . Then

$$P = C_R dT/dt \quad (1)$$

where
$$C_R = \frac{C}{dR/dT} \quad (2)$$

Even if C is a constant, C_R will have a temperature dependence if dR/dT varies with temperature. For a thermistor, which has the resistance-temperature relationship

$$R = R_0 e^{(b/T - b/T_0)} \quad (3)$$

$$dR/dT = -RbT^{-2} \quad (4)$$

R is the thermistor resistance at an absolute temperature T ,

R_0 is the thermistor resistance at temperature T_0 (often taken as 298°K), and b is a constant.

From Eqns (2), (3) and (4),

$$C_R = -CbR^{-1} \left(\ln R - \ln R_0 + \frac{b}{T_0} \right)^{-2}$$

The main source of variation of C_R with temperature is the R term which gives about a 3 to 5% change per degree centigrade at room temperature, depending upon the type of thermistor. The $\ln R$ term makes a much smaller contribution. If C_S is the 'heat capacity' at a thermistor resistance R_S (usually taken as some convenient value near the centre of the temperatures to be measured)

$$(C_R R)^{-1/2} = (C_S R_S)^{-1/2} (1 + k \ln R/R_S)$$

where
$$k = \left(\ln R_S - \ln R_0 + \frac{b}{T_0} \right)^{-1}$$

This equation is that of a straight line for the relation $(C_R R)^{-1/2}$ to $\ln R/R_S$, and may be conveniently and accurately fitted by the method of least squares, to obtain both the slope and the intercept.

Experimental results

The above principle was tested with an adiabatic calorimeter (Larson and Myers, unpublished report HW 69203) plotting $(C_R R)^{-1/2}$ against $\ln R/R_S$ (Fig. 1). C_R was determined using Eqn (1) by measuring dR/dt for a known power input. The accuracy of the power input was limited by the accuracy of the calorimeter heating coil resistance measurements ($\pm 0.05\%$) and the accuracy of the current supply.

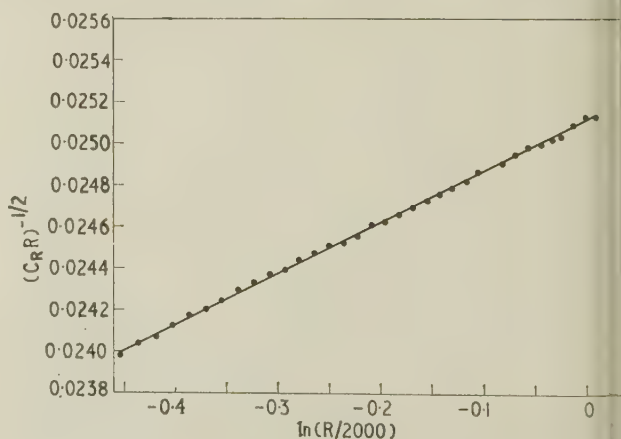


Fig. 1.

0.02%). The voltage across the heating coil resistance independently measured with a digital voltmeter; agreement between the two measurements of power was within 0.05%.

The quantity dR/dt was measured with a standard Wheatstone bridge, using a 100 μ v full scale strip chart recorder and a galvanometer. This permitted a minimum resistance change of 0.005 ohm in 2000 ohms to be detected. This was equivalent to a temperature sensitivity of about 6×10^{-5} deg C. The accuracy of dR/dt , for a heat input of 8 mw, was to approximately 0.05%.

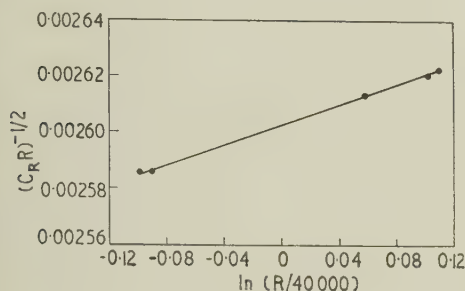


Fig. 2.

A least squares fit to the data gave 0.025127 for the intercept and 0.002505 for the slope. This was using a type 51A1 thermistor (Victory Engineering Corporation, New York), with a nominal resistance of 2500 ohms at 25° C, and a nominal temperature coefficient of resistivity of -0.039 . The resistance was taken as 2000 ohms. The experimentally measured value of k , which is the ratio of the slope to the intercept as obtained by the method of least squares, was 0.00997. The parameter k may also be computed from the thermistor specifications (see Eqn (7)). However, since these specifications normally have rather wide limits, it is probably better to do precise work to measure k directly.

A second calorimeter (W. H. Le Blanc, I. T. Myers and M. Fleming, unpublished report HW 66262), utilizing a

different type of thermistor, was also used (see Fig. 2). In this case, C_R was determined using Eqn (1) by measuring dR/dt with a standard half-gramme radium source in the calorimeter. The heat output of the source had been measured earlier (W. H. Le Blanc and I. T. Myers, unpublished report HW 67244 (1960)) to be 85.55 mw. The quantity dR/dt was measured with a standard Wheatstone bridge circuit with a sensitivity of about one part in 400000. The accuracy of dR/dt measurements was to about $\pm 0.05\%$. A least squares fit of these data to Eqn (6) gave 0.0026028 for the intercept, 0.0001805 for the slope and 0.0693 for the value of k . This was for a type 51A1 thermistor with a nominal resistance of 100000 ohms at 25° C, and a nominal temperature coefficient of resistivity of -0.046 .

For larger temperature ranges, it is necessary to integrate to obtain the total heat input Q to the calorimeter. The result of this integration is:

$$Q = \int_{R_1}^{R_2} C_R dR = \frac{C_S R_S \ln R_1/R_2}{(1 + k \ln R_2/R_S)(1 + k \ln R_1/R_S)}.$$

If the thermistor resistance change is small, the simpler expression $Q = \bar{C}_R \Delta R$ may be used. For example, during the electrical calibrations mentioned above ($\Delta R = 10$ ohms, $\Delta R/R = 0.005$) the difference between the integrated expression and $\bar{C}_R \Delta R$ was always less than 0.0004% which for most work would be completely negligible.

Acknowledgments

The authors are indebted to K. F. Baldrige for technical assistance, and to W. C. Roesch for suggesting the integration of the thermistor equation.

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Improved microfurnace power supply

by J. H. WELCH, M.A., Department of Scientific and Industrial Research, Building Research Station, Garston, Watford, Herts.

MS. received 24th March 1961, in revised form 19th June 1961

Abstract

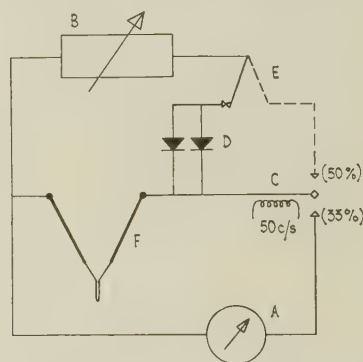
A previously described hot-stage device for high-temperature microscopy, in which specimens are supported by a thermocouple used both for heating and temperature measurement, uses a high-speed switch to interrupt the heating current at intervals during which temperature measurement takes place. Interruption of the heating current by silicon rectifiers minimizes maintenance problems and inaccuracies of temperature measurement which may arise with mechanical switching. Precautions for avoiding other sources of inaccuracy in temperature measurement are also described.

MICROFURNACE techniques using electrically heated thermocouples for specimen support, heating, and temperature measurement are finding increasing application in the study of materials at high temperatures by microscopy (Welch 1954) or x-ray diffraction (Aruja *et al.* 1959). Two methods have been described for the measurement of thermocouple e.m.f. in the presence of the superimposed heating current. The first, due to Ordway (1952), requires an oscillator and power amplifier to produce low radio-frequency heating current which can be eliminated from the temperature measurement circuit by a low-pass filter. The second uses mains-frequency heating current, interrupted by a synchronous switch during alternate half-cycles in which temperature measurement takes place. This method, which was described in a previous paper by the present author (Welch 1954) has considerable advantages in cheapness and simplicity, and has been widely adopted. It had, however, some disadvantages which have been overcome.

The relay used for switching (Siemens type H89B) required periodic checks and adjustments to prevent arcing at the current-carrying contacts. Such arcing led to eventual contact deterioration and encouraged the production of stray thermals by heat transfer through the single-pole changeover contact assembly, with consequent errors in temperature measurement. The latter trouble may be eliminated by using two separate relays, or a single relay having double-pole contacts.

A simple and effective remedy for both these particular difficulties, however, is the use of diffused junction silicon rectifiers to interrupt the heating current in place of mechanical switching (Welch 1959), which is retained solely for operating the temperature measurement circuit. Such rectifiers are characterized by very small reverse leakage current, especially at the low voltages in the present application. Type 1S401 rectifiers (Texas Instruments Ltd.) were found to be particularly suitable in this respect; with an applied reverse voltage of 10 v the leakage current was undetectable on a galvanometer sufficiently sensitive to measure temperature differences of 0.1 deg C in the high-

temperature range of 5%Rh-Pt/20%Rh-Pt thermocouple. To ensure that the leakage current, which rises with operating temperature, is kept to a minimum, two 1S401 rectifiers in parallel connection and mounted at 2 in. centres on blackened aluminium heat sink 4 in. $\times$ 2 in. $\times$ $\frac{1}{16}$ in. were used. On equipment as previously described (Welch 1954) the addition of a two-way switch (see Figure) allows the original relay contact functions to be restored temporarily during the initial contact phasing and timing adjustments. As distinct from former practice considerable latitude of adjustment is permissible and contact bounce is of little consequence. It is recommended that the original power handling contacts should be set for 50% closure time to facilitate the phasing operation, and the temperature measuring contacts for about 33% ($\pm 5\%$). Thereafter no further checks or adjustments should be required.



Block diagram showing modified microfurnace power supply. A, temperature measuring instrument; B, variable low-voltage power supply (50 c/s); C, polarized relay (single-pole change-over); D, silicon rectifiers; E, two-way switch for relay adjustment; F, thermocouple/heater.

These alterations not only eliminate mechanical adjustments and stray thermals, but temperature variations of the heated thermocouple arising from drift in contact timing are also removed. As the silicon rectifiers exhibit negligible warm-up drift and extremely stable behaviour, thermocouple temperatures can be maintained over long periods within limits determined only by the stability of the supply voltage and frequency. Using an inexpensive constant-voltage transformer (Advance Type CV100A), which is voltage-stable but not frequency-stable, thermocouple temperatures of 1500°C have been maintained continuously within ± 3 deg over hours and within ± 6 deg for 1 week.

It should be emphasized that accuracy of temperature measurement using mains-frequency switching method requires precautions for the avoidance of inductive coupling

stray magnetic fields, which are unnecessary in the way technique. This is because small induced currents at mains frequency introduce corresponding d.c. components in the temperature measuring circuit resulting from the synchronous operation of the switch. The presence of induced e.m.f. may be detected readily by means of a dummy thermocouple load, using identical alloys (e.g. 20% Rh-Pt), at both heater legs. Such a heater should register zero e.m.f. in the measuring circuit for any operating temperature. Using a wiring layout designed to avoid the creation of inductive loops (i.e. single-cored coaxially screened cable from thermocouple to relay and from relay to measuring instrument, using coaxial type connectors at intermediate points as required), only the relay itself should require attention. There are now various commercially available d.c. relays for operation at mains frequency that may be used in this application, since they have been specifically designed to avoid inductive coupling between the actuating coils and the contact assembly. One such chopper that has been successfully utilized in more recently constructed equipment is the Synchronising Synchronizer. This is a polarized relay, and the version used has dwell times of 33% on each changeover contact pair. The chopper is designed to operate at 6.3 v a.c. and the use of a subsidiary transformer to supply this voltage may be avoided by driving the operating coil in series with a 3900 Ω 10 w resistor from the mains supply. This arrangement minimizes phase lag in the contact operation and the residual phase lag may be removed by inserting a 25 μ F capacitor in parallel with the series resistor. The Synchronising high-speed relay is still the cheapest form of chopper available and, on existing equipment provided with the necessary polarizing and phasing circuits, it may be retained

with slight modification. It has been found that the standard contact connections are rather vulnerable to pick-up from the actuating coils. To avoid this, a short flying lead of 36 s.w.g. enamelled copper wire is soldered to the tip of the moving contact spring; this wire is then coiled into two or three turns approximately $\frac{1}{16}$ in. diameter, and the free end is soldered to a tag supported by, but insulated from, one of the fixed contact clamping screws. A second uninsulated tag held by the same screw provides a connection to the fixed contact, and the two closely-spaced tags are used for connection to the screened cable forming a part of the temperature measurement circuit.

These modifications to the equipment as originally described have reduced stray e.m.f.s to a level of 2 or 3 μ V, as well as making operation much simpler and completely reliable.

Acknowledgment

The work described in this paper was undertaken as part of the research programme of the Building Research Board of the Department of Scientific and Industrial Research; the paper is published by permission of the Director of Building Research and Crown copyright is reserved.

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Systematic operational testing of the von Eller optical synthesis machine

by J. C. COPPOLA, A.B., M.S., Department of Chemical Crystallography, University College, London, W.C.1

MS. received 26th August 1960, in revised form 4th July 1961

Abstract

The von Eller optical synthesis machine gives the photographic sum of a large number of terms of a Fourier series. Several critically located components on the instrument can easily get out of adjustment, simply through normal use. A procedure is described for taking three photographs to define that part of the instrument in need of adjustment and the amount of correction necessary.

THE optical synthesis machine of G. von Eller (1955)* can be used for photographically summing a large number of Fourier series terms of the type

$$\rho_{\mathbf{r}} = \sum_{\mathbf{s}} F_{\mathbf{s}} \cos (2\pi \mathbf{r} \cdot \mathbf{s} + \alpha_{\mathbf{s}}).$$

Over a long period of use, the von Eller machine often requires adjustment in one or more of its critically located parts, and should be regularly checked.

Diffraction grating and light source

Optical summations which lack the required plane-group symmetry can be caused by a displacement, either of the light source from the rotation axis of the drum or of the diffraction grating from its original central position. Whereas lack of symmetry is the only symptom of the latter misadjustment, displacement of the light source also results in a blurred or fuzzy image near the edge of the photograph, similar to a picture taken by means of a lens suffering from spherical

aberration. The two sources of error can be quickly distinguished by taking two photographs.

(1) A photograph is taken with the diffraction grating at its greatest distance from the light source, phase angle setting at zero and the shutter on the film holder closed half-way. A second exposure is made on the same film with the drum rotated through 180° and the shutter completely open, but with the previously exposed half of the film covered up. Both light source and diffraction grating are in proper adjustment, a photograph will be obtained similar to Fig. 1. If, however, either source or grating is out of alignment, the photograph obtained will resemble Fig. 2, the amount of mis-matching of the fringes being proportional to the

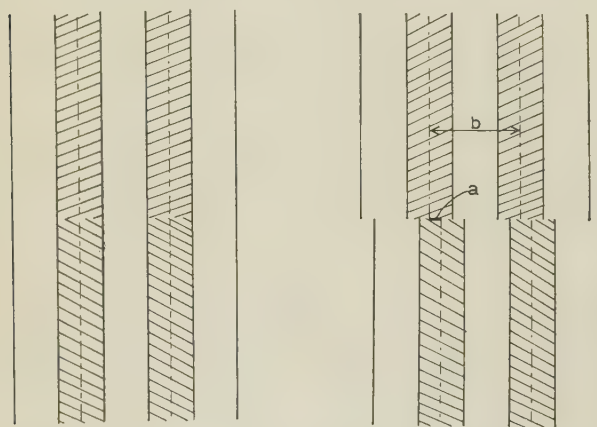


Fig. 1. Coincident fringes; no adjustments necessary.

Fig. 2. Non-coincident fringes; adjustment needed in light source or diffraction grating.

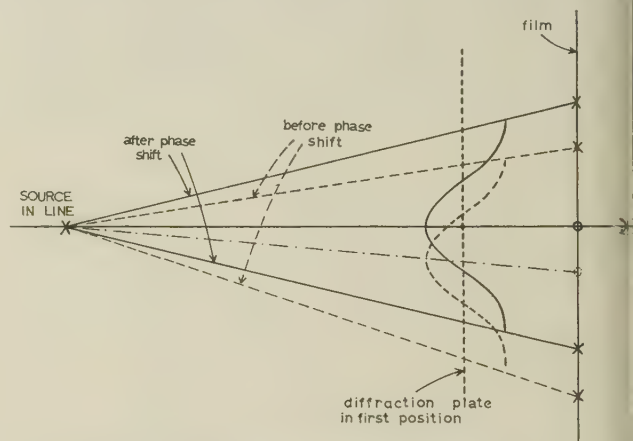


Fig. 3. First photograph; non-coincident fringes. Diffraction grating needs adjustment.

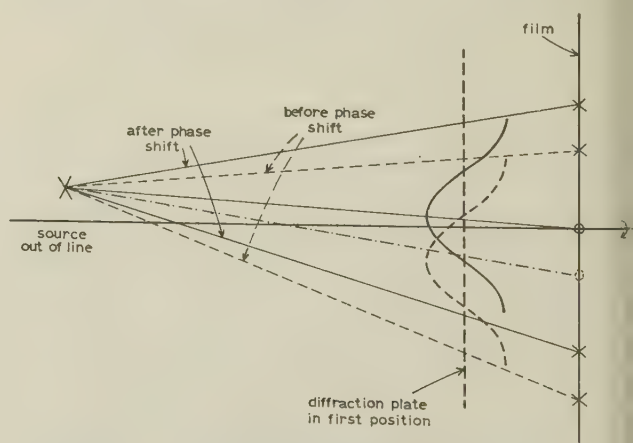


Fig. 4. First photograph; non-coincident fringes. Light source needs adjustment.

* VON ELLER, G. Premier Thesis, Faculté des Sciences de l'Université de Paris (1955).

placement of either light source or diffraction grating. The fringes can be brought into coincidence by measuring the distance between the fringes in the first photograph and changing the phase angle setting correspondingly (Figs 3 and 4). The measurements required are the displacement of the fringes obtained by 180° drum rotation, and b , the fringe wavelength. Then $\pi a/b$ is the amount in radians which the phase angle must be shifted to bring the two sets of fringes into coincidence; the direction of shift can be deduced from the photograph.

(2) The second photograph differentiates between the sources of error; with the diffraction grating near to the light source, the procedure used in taking the first photograph is repeated. If the fringes once more do not coincide upon rotating the film holder 180° , the light source is out of position and should be corrected by an amount Rd/t , where R and t are the distances of the diffraction grating from the light source and film respectively and d is the displacement of the central fringe from the axis of the drum. If, however, the fringes are coincident upon rotation by 180° of the film holder, the adjustment needed is in the position of the diffraction grating perpendicular to the optical bench, the amount of adjustment being $a/2b$ times the fringe width of the diffraction grating itself.

Scaling and the reciprocal lattice point cursor

It is essential that in summing the various diffracted orders sketched on the reciprocal lattice net, a strictly linear relationship is maintained between the vertical movement of the cursor and the traverse of the diffraction grating parallel to the optical bench. This relationship can be quickly checked with one photograph to ensure that the distance of the cursor from the origin is directly proportional to the number of fringes per unit distance produced on the film. Several exposures are made on a single film: at each exposure the position of the diffraction grating is varied (cursor position being noted) and the drum is placed in a different angular position. The photograph (Fig. 5) should show sets of fringes, the reciprocals of whose widths are linear functions of the settings as noted on the cursor (Fig. 6). If the line plotted is extrapolated back towards the origin, it should intersect the ordinate axis at zero, if the cursor scale is properly set. A non-zero intersection is unimportant and merely means that the cursor scale should not be used directly for laying-off reciprocal lattice distances. Any departure of the plot from linearity, however, is of importance and the linkage between the movement of the diffraction grating and the cursor should be thoroughly examined and adjusted.

The reciprocal of the slope gives the amount by which the

reciprocal lattice distances when plotted (in reciprocal centimetres) in the net must be multiplied to give the desired unit of measurement in the photograph. Though any scale

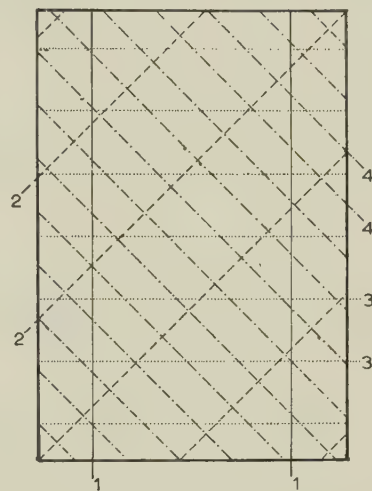


Fig. 5. Schematic diagram of test photograph for cursor—fringe width relation.

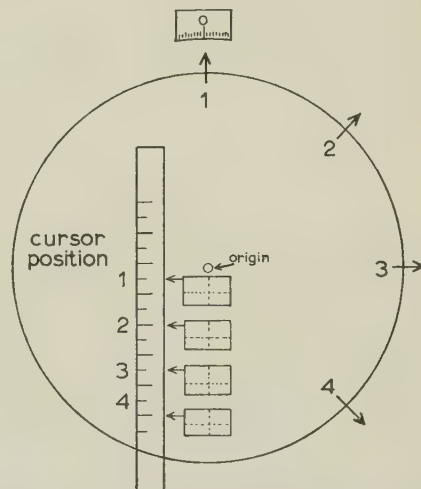


Fig. 6. Cursor and drum settings to obtain test photograph for cursor adjustment.

could be used, it is very convenient to have one centimetre in the photograph corresponding to one ångström unit in the unit cell.

Instrument for cutting animal tissues into small pieces ($<3\text{ mm}^3$) with preservation of viable cells

by A. L. SIMS, Physiology Institute, University College, University of Wales, Newport Road, Cardiff

MS. received 20th June 1961, in revised form 14th July 1961

Abstract

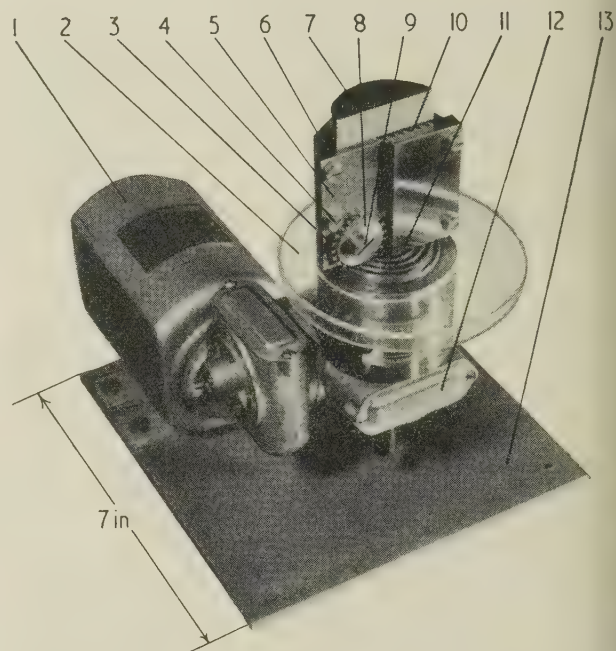
This instrument is designed to cut animal tissue into minute pieces (about 3 mm^3) with the minimum of crushing of cells. Cutting is by a continuous scissor-like shearing action and the instrument is self-sharpening. A steel disk with a spiral groove cut in one face is rotated horizontally below a vertical rectangular steel plate. Cutting takes place when tissue in a specially shaped container is pressed by a sliding weight into the groove of the spiral and upon rotation is carried against the sharp toothed edge of the stationary rectangular vertical steel plate. The cut pieces in the spiral groove are removed by a gear wheel in continuous mesh, and fall into a catch tray. The size of the pieces cut is governed by three factors; (i) the width and depth of the spiral groove, (ii) the weight pressure and (iii) the spacing of the buttress-shaped teeth along the cutting plate edge.

Principle and design

THE staff of a virological laboratory found that one of their most difficult tasks was to cut diseased human thyroid into small pieces which could be kept alive by incubation. Knives and scissors were used by hand for this purpose but owing to the physical nature of the tissue the task was laborious.

The foundation of the instrument is a metal table with four rubber legs. Fitted to this table is a fractional h.p. electric motor, with a double reduction gear box attached to one end plate, the final driving spindle projecting from the gear box in the vertical plane. To the top of this spindle is fitted a metal disk with a spiral groove cut in its upper surface. A half cylindrical metal container is built to stand over the spiral groove and the half cylinder is closed by screwing a hardened and ground rectangular steel plate across the two cut surfaces of the cylinder. This cutting plate is so arranged that it rests in a downward direction on top of, and in permanent contact with, the crests of the spiral groove. Tissue to be cut is placed in the container and pressed against the cutter by a metal weight which loosely fits the container. The weight presses some of the tissue down into the grooves of the spiral and rotation of the spiral carries this tissue in the groove against the sharp edges of the teeth formed on the inside bottom edge of the cutting plate where it is cut off from the main body of the tissue in the container. The cut tissue, still in the spiral groove now passes under the edge of the cutting plate and outside the container where it is removed by the teeth of a gear wheel so situated that it remains in continuous mesh with the spiral groove. A circular catch tray surrounds the cutting position and collects the pieces as they come out from the spiral groove.

It was also found during construction that the instrument



General view of instrument. 1, electric motor, 240 v, 50 c/s a.c., 30 lb/in. torque; 2, catch tray, made from a plastic Petri dish; 3, stainless-steel pins; 4, screws (4 B.A.); 5, cutting plate; 6, container; 7, brass weight (12.25 oz.) fitting loosely into container; 8, gear wheel; 9, gear wheel fixing screw; 10, teeth of cutting plate; 11, spiral cutting unit; 12, gear box (final spindle speed 10 rev/min); 13, duralumin base plate, 7 in. $\times$ 6.5 in. $\times$ 0.25 in. with four rubber feet.

could cut a wide range of other materials, including rubbers, grasses, ivory, plastics, etc., and in suitable circumstances even some soft non-ferrous metals.

Construction

The various features of the instrument are shown in the photograph.

The spiral cutting unit 11 is a steel disk 1.625 in. in diameter $\times$ 0.25 in. thick. It is machined from the solid having a boss projecting from its under side. A hole is bored in the boss to fit the vertical spindle of the gear box and the spiral cutting unit is locked to the spindle with an Allen screw. Cut in the upper surface of the steel disk is a spiral groove 0.125 in. pitch, and 0.0625 in. wide and deep respectively. One side of the groove is undercut so that it presents an angular face for cutting, of similar form to a buttress thread. The spiral groove has been cut on the lathe with a tool set into a 0.5 in. diameter recess which was pre-formed for this purpose. The change wheels on the lathe were arranged to give a pitch of

5 in. to the cross slide and the spiral groove was cut in a similar manner to that employed when cutting a square rod on a metal cylinder. After the rectangular shaped groove was completed its outer side was undercut to an angle of 5° from the vertical giving an angle of 75° to the spiral component of the cutter.

The cutting plate 5 is of hardened and ground cast steel, 1.75 in. wide × 2 in. height × 0.25 in. thickness. It is rigidly held on the two cut faces of the container by four screws, 4. In order to ensure that the bottom edge of the cutting plate remains in permanent contact with the crests of the spiral cutting unit the fixing screws pass through vertical slots cut in the plate. Half of the area of the cutting plate inside the container is provided with a vertical rack and pinion 10. These are cut at an angle at 45°, 0.125 in. deep × 0.125 in. apart; they were cut before the plate was hardened.

The gear wheel 8 is made of brass, the teeth consisting of stainless-steel pins 0.0625 in. diameter are inserted around the periphery of the wheel. In order that the gear wheel should mesh on a line across the axis of the spiral cutting unit a portion of the cutting plate surface is removed to make this possible.

Performance

During trials of the finished instrument it was found that a wide variety of materials could be cut, including some animal vegetable and mineral matter. Synthetic rubber is cut with the utmost ease and quickness using a weight of 12 oz. but pieces of a soft metal require a weight of many pounds. In order to operate the instrument it is necessary to have the material to be comminuted reduced to a size which will enter the container easily and also leave room at the top for the weight. Having done this it only requires the electric motor to be switched on when the pieces will automatically fall into the collecting tray until the base of the loosely fitting weight itself reaches the spiral crests. As an indication of its performance a $\frac{1}{2}$ in. cube of a gum rubber office eraser is comminuted in one minute, the average size of the pieces being 3 mm.

Acknowledgments

I wish to express my thanks to Professor J. M. Peterson and Dr. C. R. K. Blundell for helpful suggestions and also to Mr. D. H. Brown and Mr. D. M. Warman for making the instrument and to Mr. R. A. Boothby the photographer.

Notes and Comments

Optical Industry Directory

The Optical Publishing Company, Lenox, Massachusetts, announces the publication of the seventh (1961) issue of the *Optical Industry Directory*. This gives a list of the thousand companies in America who manufacture instruments and components and supply services available from the optical industry. The lists are categorized under 350 item groupings. A revised lens appendix gives information concerning a thousand commercially available lenses for photography and optical instrumentation. The Directory may be obtained from The Optical Publishing Company, Box 1753, Lenox, Massachusetts. There are 200 pages. The price is \$7.50.

International Conference on crystal lattice defects

An International Conference on crystal lattice defects will be held in Kyoto, Japan, from 7th–12th September 1962. The Conference is being organized by the Physical Society of Japan. The International Union of Pure and Applied Physics is considering sponsorship of the Conference.

The Conference will cover point defects in metals, semiconductors and ionic crystals, as well as extended defects closely related to point defects. Suggested items of discussion are, for instance, electronic processes in imperfect

crystals, properties of single and multiple point defects, radiation damage, association, dissociation and diffusion of point defects. Purely phenomenological studies will not be included, nor work that is ambiguous from the viewpoint of lattice defects.

The attendance will be limited to actually active research workers in the field of lattice defects, and others who may be preparing to enter work in this field. The meeting will be arranged to reserve ample time for discussions. The language used will be English.

All correspondence should be addressed to: Lattice Defects Conference Secretariate, c/o Prof. R. R. Hasiguti, Department of Metallurgy, University of Tokyo, Bunkyo-ku, Tokyo, Japan.

New British Standards

The following new British Standards have recently been issued: B.S. 3383: 1961. Normal equal-loudness contours for pure tones and normal threshold of hearing under free-field listening conditions. Price 4s. 6d. B.S. 1828: 1961. Reference tables for copper v. constantan thermocouples. Price 6s. These may be obtained from the British Standards Institution, British Standards House, 2 Park Street, London, W.1.

Anti-distortion mountings for instruments and apparatus

by R. V. JONES, M.A., D.Phil., F.Inst.P., Department of Natural Philosophy, University of Aberdeen

MS. received 13th June 1961

Abstract

Some principles for the mounting of instrument platforms are discussed. For many optical and mechanical instruments, the working platform may best be protected from external mechanical distortion by supporting or suspending the platform by members, usually three, whose stiffness is much less than that of the platform. At the same time, these members can be stiff enough to give a fairly rigid location. Some possible arrangements are outlined.

THERE are many instances where the satisfactory functioning of an instrument depends upon the maintenance of an exact spatial relationship between its parts, but where the position of the instrument as a whole relative to its surroundings is of much less importance. For example, instruments such as comparators, measuring microscopes, optical benches, and microbarographs are of this type; whilst theodolites and cathetometers are not. The considerations of this paper apply mainly to the former type.

The usual way of ensuring accurately maintained geometry is to design a substantial platform, with appropriate supports for the individual components. This platform has, however, usually to rest on something else directly or indirectly attached to the earth's surface, such as a table or pillar or perhaps the exterior case of the instrument. It frequently happens that there are unavoidable and fluctuating distortions in the external support, which may be transmitted to the instrument platform, causing it to warp or bend elastically. Even with the strongest platforms that it is feasible to construct, these effects can sometimes be serious when the instruments are intended to measure displacements of the order of a micron or less; but not much attention appears to have been given to the problem of minimizing them.

To reduce the effect of mechanical distortion there are two standard approaches. The first is to mount the instrument platform on a single 'stalk', which is usually supported by a base with tripod feet. Any distorting effects in the external support which are transmitted to the base tend to make the stalk move bodily, carrying with it the instrument platform as an undistorted unit. This is true so long as the only link between the platform and the external support is through the stalk. The device is commonly found among older types of optical instruments, such as spectrometers and interferometers, where the stalk may thus have served a purpose additional to that of raising the platform to a convenient working height. The stalk principle is not, however, always applicable, particularly where the available height is limited, or the weight distribution is unsuitable; moreover, if the adjustment of the instrument involves contact between the operator's hand and the platform, the latter may flex undesirably under the variable bending moment set up between the operator's hand and the stalk.

The second standard approach is to provide contact

between the instrument platform and the external support at three points only, usually by short levelling screws or pads. This measure is sound, on kinematic grounds, but it is not always feasible or sufficient. It is not always advisable, for example, when the centre of gravity of the instrument, as seen from above, lies near an edge of the triangle formed by the three feet. The measure is not sufficient if the dimensions of the external support change relative to those of the instrument base, due to some cause such as temperature fluctuations, or to additional weights being placed on some other part of the support. The expansion or contraction of the support relative to the instrument base will result in some distortion being set up in the base due to forces being transmitted by friction through the contacts. Such distortion could be minimized by replacing the levelling screws or pads with freely rolling balls, but this solution is rarely feasible because the instrument would then be altogether too free, and in any event the balls may not roll until there are appreciable sideways forces acting on them, and hence on the instrument base.

A more promising approach is to replace the contacts with partially flexible connections fixed both to the instrument platform and to some exterior framework, so as to suspend or support the platform. If the relevant stiffnesses of the platform and the connections to a particular distortion are S_p and S_c , the distortion occurring in the platform is only $S_c/(S_p + S_c)$ of the total distortion occurring in the external support. Most of any relative change in dimensions of the external support and the instrument platform can thus be taken up by the flexing of the connections, provided that the ratio S_c/S_p is made small. With most well designed platforms, this ratio can be made smaller than 0.01 without the connections having to be very flexible; indeed, the instrument platform can be quite stiffly supported but still have sufficient compliance in its supports to render the platform sensible free from external distortion.

The quantities to be borne in mind for design are those such as the ratio l^3/ab^3 , where l is the length of the member subjected to bending, a its width and b the thickness resisting bending. Provided that this ratio for the flexing connections is large compared with the corresponding ratio for the instrument platform, the latter is effectively protected from distortion. Supposing, for example, that the instrument platform is 30 cm square by 2 cm thick, this ratio is of the order of 100. For the connections, the ratio should be made of the order of, say, 10000, making them 100 times more flexible than the platform. If the connections are made of the same material as the platform, and are to be 1 cm long by 1 cm wide, their thickness would thus have to be not more than about 0.4 mm. Even so, they would make quite strong supports.

The flexing connections can be either rods or strips, either in tension or in compression. Some of the possible arrangements are illustrated in the Figure; the instrument platform

assumed to be rectangular, and the connections to the form are shown. The other ends of the connections are assumed to be fixed to the external framework, which is not shown. In applications where the direction of the external distortion cannot be predicted, arrangements using three rods are commonly, large diameter wires) such as A and B are

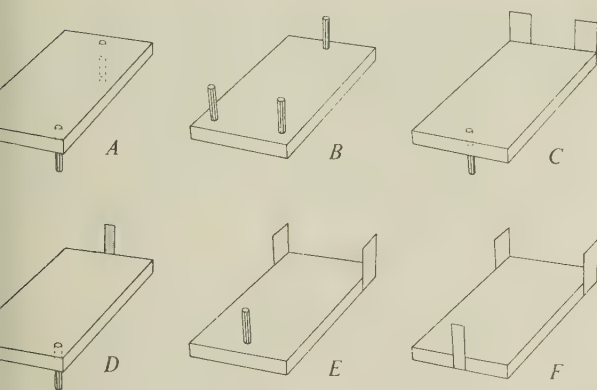


Figure 1. Some alternative arrangements for anti-distortion mountings (not to scale), using strips or rods as flexing connections between the platform and the exterior framework (not shown).

particularly suitable. If, however, the character of the most likely distortion is known, or if it is necessary only to protect the instrument against one particular distortion, then the connections may be designed to be specifically weak in the appropriate direction. For example, in a microbarograph having a long rectangular base which the author recently designed the one important distortion was that of 'arching' along the length of the base. The connections had therefore to be weakest in this direction; and arrangement C was adopted very successfully, even though displacement of the order of 10^{-7} cm in 20 cm length would have been appreciable.

The arrangement shown in A (see Figure) was used satisfactorily in a recent experiment where the instrument platform was to be protected against distortions of the order of 10^{-6} cm.

In another application, where the source of external distortion was the bending of the wooden bench supporting the instrument, it was known that the result would be a twist in the instrument platform along the direction of its longest axis. In this instance, arrangement F was used. The platform was made of 10 s.w.g. aluminium, bent into a section 45 cm wide by 6 cm high, and 80 cm long, thus giving a horizontal working surface of 80 cm by 45 cm. The nearest strip shown in the diagram was 3 mm wide by 3 mm thick; the other two were 25 mm wide by 0.18 mm thick. All these strips had a free length of 25 mm, and were made of beryllium copper; they were suspended from an external frame of Dexion resting on the wooden bench. The platform would comfortably take a weight of 30 kg; it felt surprisingly rigidly suspended, despite the slenderness of the strips. The effectiveness of the suspension was tested by placing weights on the wooden bench, and measuring the resultant warping of the Dexion frame and the aluminium

platform about an axis parallel to the longest edges of the platform. The warping in the platform was only about one five-hundredth of that in the frame. This result was confirmed by operating an actual instrument (an optical lever, where distortion can be troublesome) first directly on the wooden table and then on the platform, and measuring the improvement in stability. Incidentally, the improvement obtained by supporting the instrument on a rigid 'kinematic' three-point base in contact with the wooden table was ten times poorer than that obtained with the flexibly suspended platform.

While insufficient trials have so far been made to justify a firm conclusion, arrangement F may be the one that is most generally useful. At the same time, the arrangements illustrated are not exhaustive; the principle can be applied in many different forms. All that matters is that the connections should be appreciably more flexible than the instrument platform, particularly in the directions in which relative changes in dimensions are likely to occur. The instrument base can thus be protected against the distorting influences due to displacements of the individual supports; at the same time it is effectively anchored, so that even if the support and the platform were turned on their sides, there would be sufficient stiffness in the connections for the platform not to move very far. This is particularly valuable in portable instruments.

A further advantage is that the platform will not tip over unless the centre of gravity of the instrument falls well outside the triangle joining the supports; it is thus safer than a kinematically supported platform. If necessary, four supports can sometimes be used instead of three, provided that they are reasonably chosen.

It is often necessary to make hand adjustments of devices such as micrometers on the instrument platform. If the connections are sufficiently stiff, these adjustments are no more difficult than on a rigidly mounted platform, since the 'give' in the platform is relatively small, and the variable bending moment introduced between the operator's hand and the nearest support can be made small by placing the support near the micrometer. The adjustment can often be made more precisely if it is arranged to turn the micrometer not directly, but through a subsidiary shaft which is mounted on the 'earthed' side of the connections, and which drives the micrometer shaft in such a way as to transmit rotation only—a slotted keyway extension to the micrometer making contact with a pin on the driving shaft is one way of effecting this.

This principle of flexing connection as an insulation against distortion is not quite the same as anti-vibration mounting, although such mounting provides incidentally against platform distortion. It may, however, be both inconvenient and unnecessary to have the great flexibility inherent in a low-frequency anti-vibration mounting, and in such instances the type of mounting described in this note may be very useful.

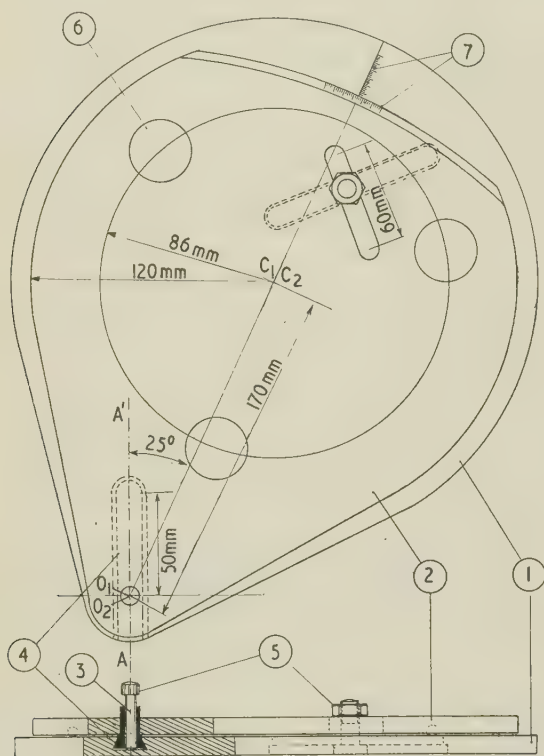
The principle does not seem to have been specifically expressed in current standard works on instrument design but, as Dr. A. H. Holbourn has pointed out to me, it is possible that Rowland deliberately used it. He mounted his diffraction grating engine on three spindle-like legs, and the most reasonable explanation is that he intended thereby to accommodate any change of dimensions in the external support.

On the adjusting of the de Wolff type Guinier camera

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MS. received 26th May 1961

As mentioned by Fischmeister (1961) the use of Guinier cameras in industrial work is restricted by the complications of adjustment. For the de Wolff (1948) type Guinier camera



The base of the de Wolff type Guinier camera. 1, fixed part; 2, moving part; 3, axis of rotation; 4, the groove for the axis movement; 5, fastening screw; 6, hole for the camera leg; 7, millimetre scale.

all Fischmeister's requirements (with the exception of the vertical adjustment) can easily be met by a simple base described here. In order to achieve easy adjustment we have assured

- (i) a reproducible rotation of the whole camera around an axis lying at the centre of the monochromator, perpendicular to the primary beam and the reflecting plane normal,
- (ii) a reproducible shift of this axis along the primary beam.

To realize these we have mounted the camera on a base consisting of two parts (see Figure). The lower part is fixed to the platform of the x-ray source so that its median (O_1C_1) should make an angle of 25° with the primary beam (AA'). The horizontal distance between O_1 and the tube focus is about 110 mm (this is the monochromator distance for CuK_α). The camera is mounted on the moving part, with the centre of the monochromator just above the axis of rotation (O_2) which has a groove in the fixed part, parallel with the primary beam. The reproducibility of the movements is ensured by arbitrary millimetre scales on both parts.

Adjustment is effected as follows: the axis is put in the position determined by the wavelength and the crystal (for example, Rose 1957). Then the monochromatized beam is obtained by rotating the monochromator, and the whole camera rotated around O_2 until the focus also falls into the right position.

The camera, after operation with CuK_α radiation, can be readjusted in this way for FeK_α radiations (including tube exchange, etc.) in twenty minutes.

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Simple storage method for thin self-supporting carbon films

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MS. received 31st July 1961

The demand for thin carbon films as targets, backings and beam strippers, as used in the Harwell Tandem Generator, has necessitated the 'stock-piling' of films of various thicknesses.

Hitherto, by virtue of the 'Teepol' substrate—a Shell liquid detergent—the films had to be floated off their glass slides within 2–3 days of evaporation (Dearnaley 1960).

A simple method has been devised and used here for over nine months, in which the films have been stored on their glass slides until required for use.

All that is required is a large glass desiccator and a suitable vacuum bell-jar with ground glass flange. An internal frame

is made up of Perspex to hold the glass slides. The desiccator is filled with distilled water to a 2–3 in. level. Ordinary tap water was found to contain organic matter producing, with time, fungoid growths on the slides. The storage unit is assembled with its ground glass surfaces sealed with vacuum grease.

Slides have been stored successfully for a period of over six months by this water vapour storage system at Harwell with no deterioration in foil strength.

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Control of slow motion devices at motor speeds near the stalling value

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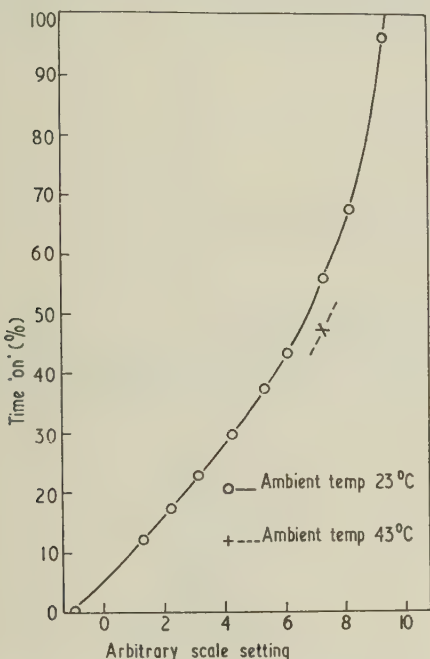
During the experimental growth of metallic single crystals, using the Bridgman technique, it was found necessary to move the sample through the melting zone of a furnace at speeds of the order of one inch per hour. For initial experiments a simple control was required to permit variation in the lowering speed from about $1\frac{1}{2}$ to $\frac{1}{2}$ in./hour.

The motor employed was a 24 v a.c./d.c. type with a reduction gear box to give a peripheral speed of $1\frac{1}{2}$ in./hour on a $\frac{5}{32}$ in. diameter shaft using a 15 v a.c. supply. It was, however, found possible to reduce this average speed by using a Sunvic energy regulator (or Simmerstat) in the 230 v supply to the 15 v transformer.

By means of this regulator (which can control a maximum of 2000 w) the motor could be switched on for any desired proportion of the time. Since the total time for the 'on-off' cycle is about 40 seconds, and the sample would move less than 0.0003 in. between each 'off' period, this should have negligible influence on the cooling rate of the charge.

The energy regulator can readily be calibrated in terms of the proportion of the 'on' period in relation to the total time for the 'on-off' cycle, and the actual lowering speed determined by simple proportion. A typical calibration curve for this is shown in the Figure. It should be noted, however, that any marked rise in the ambient temperature will cause a corresponding fall in the proportion of the 'on' part of the cycle. If the temperature is allowed to exceed about 50°C the regulator becomes virtually inoperative and does not switch on at all until the setting is more than '7'.

The table gives lowering speeds in terms of the regulator setting using 15 v motor supply.



Energy regulator setting	Lowering speed
10	$1\frac{1}{2}$ in/h
8	1 in/h
$4\frac{1}{2}$	$\frac{1}{2}$ in/h
$1\frac{1}{2}$	$\frac{1}{4}$ in/h

Thanks are expressed to Mr. J. K. Brown, Director of Research, for permission to publish this note.

Stabilized power supply for microcalorimetry

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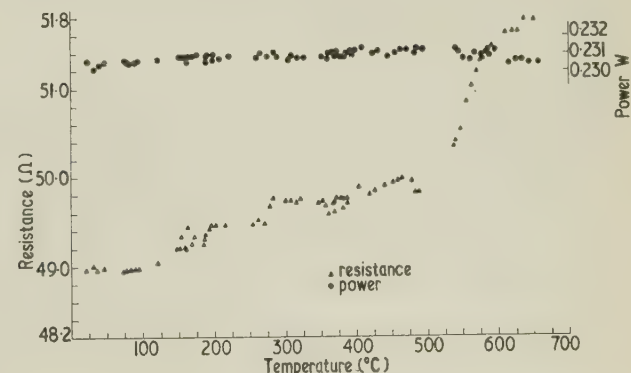
Received 20th February 1961, in revised form 4th May 1961

Abstract. It is pointed out that the power match occurring when source and load resistances are equal can be used to stabilize the power developed in the specimen heater, as an aid to 'adiabatic' calorimetry.

In so-called adiabatic calorimetry, a secondary source of heat is intimately associated with the specimen is sometimes useful as a calibration aid. If the experiment involves a wide range of temperature, the change of resistance of the component developing the power has to be taken into account, though this effect can be reduced by using a suitable resistance wire. Platinum, for instance, varies by about 10% between 0°C and 50°C.

Stabilized power units are available which in fact supply power at constant potential over a useful range of current. The source impedance over the working range is very low compared with the design load. Stabilized current supplies

are also available whose source impedance is very large compared with the design load.



The power at zero frequency developed in a resistive load goes through a maximum as its resistance varies about the value of the source resistance. It can be shown that

$$\frac{\delta w}{w} = \frac{n-1}{n+1+\delta R/R} \cdot \frac{\delta R}{R} - \frac{n}{(n+1+\delta R/R)^2} \cdot \left(\frac{\delta R}{R}\right)^2$$

where w is the power developed in the load, R is the load resistance, n is the ratio of resistances, source/load.

If the second term can be neglected, when $n = 1$, $\delta w/w = 0$, and when $n = 1.1$, $\delta w/w = 0.05 \times \delta R/R$. Thus, even if n is 10% out, which may occur with 'pyromic' wire at the ends of a very useful working range, a reduction factor of 20 on the effect on the power developed in the calorimeter by a small change of the resistance of the specimen heater can be expected.

A circuit giving a stabilized potential in the 1–10 volt range was used to feed the specimen heater through a ballast resistance about equal in value to the resistance of the heater. The specimen heater was thus fed from a source 'matched' to it, as required by the derivation, if imperfections in the stabilized potential source are neglected. The maximum ripple observed was such that the heating effect produced by the ripple current would be about 0.02% of the heating produced by the direct current.

The graph shows the results on an actual furnace. The resistance curve is not that of 'pyromic' as copper leads attached to the heater were in the hot zone and only two leads were available at the time for the specimen heater. The potentiometer used was a portable type capable of a reading accuracy to about 0.1%.

Flexible coupling and overload safety device

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The flexible coupling described here is a variation of the well-known Oldham coupling, but possesses, in addition, certain advantages.

The machining of this coupling, illustrated in Fig. 1, is

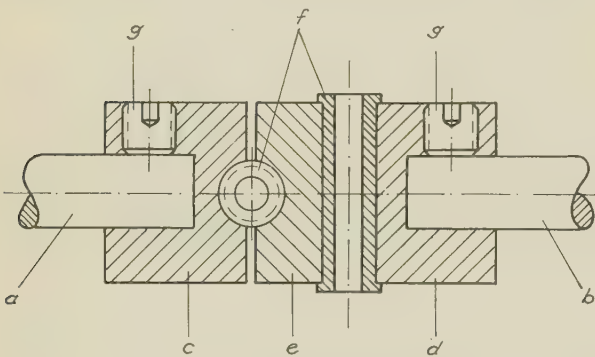


Fig. 1. The flexible coupling.

a, driving shaft; b, driven shaft; c, d, e, main parts of the coupling (brass); f, pins (hard rubber); g, set screws.

quite simple. In a piece of round brass bar a centre hole (of the same diameter as the shafts) as well as two radial holes (offset by 90°, for the pins) are drilled and the holes for the set screws are drilled and tapped. Finally the piece is sawn into three parts. The pins are simple turnings made from hard rubber.

The coupling allows angular disalignment between the driving and driven shaft as well as radial, and to a slight extent, axial displacement of the shafts. Another feature of the coupling is that it limits the possible transmitted torque and in this way acts as a safety device when overloaded. For instance, if parts on the driven side should seize, then the pins f —usually only one of them—are broken, and the coupling disconnects.

Measurements of the breaking torque M_b (static) for typical size of the coupling were made with hollow pins of hard rubber (Fig. 2). The values of the torque, as a function

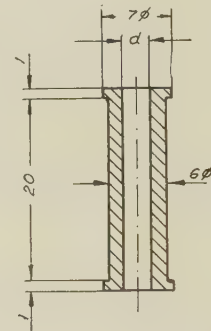


Fig. 2. Dimensions (in mm) of the pins f in the breaking-torque experiment. ϕ = diameter.

of the inner diameter d of the pins, are tabulated below. The results are averages of five experiments with each size. Q is the axial thrust (calculated) at breaking point, for 1 mm gap between c and e .

d (mm)	M_b (kg cm)	Q (kg)
1.0	215	36
2.0	155	26
3.0	103	17
4.0	51	9
4.5	31	5

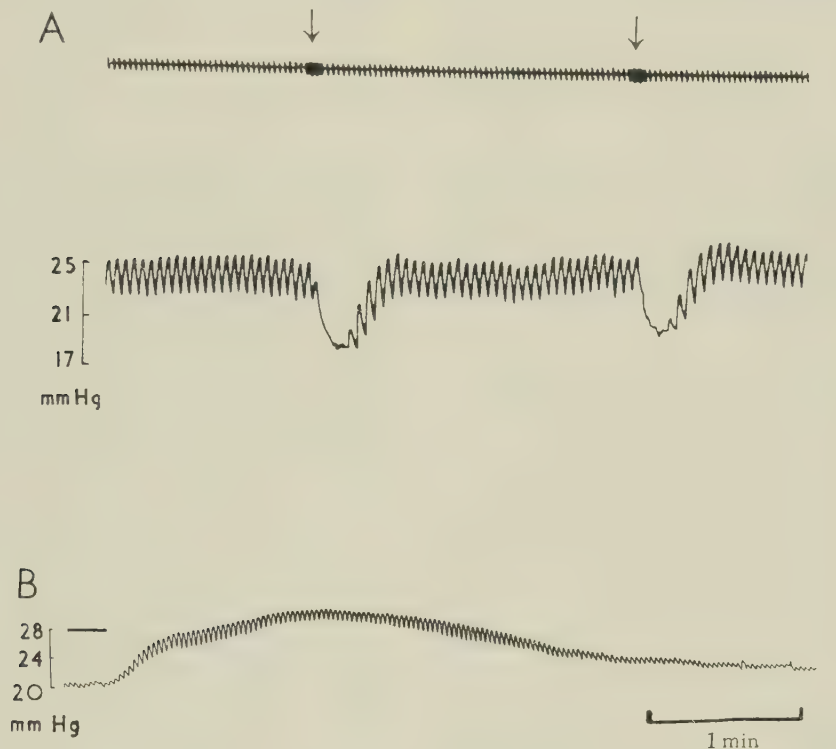
As is seen from the column Q , apparatus using this type of coupling should have good bearings, suitable for taking end-thrusts.

A simple electromanometer utilizing the CdS photoconductive cell

In biological studies, it is often required to convert changes in pressure or tensile force into those of electric force in order to observe them simultaneously with other phenomena. So far, strain gauges, capacitance transducers, mechanoelectric transducers (RCA 5734), etc., have mainly been employed for this purpose. Although these instruments are very good in many respects, they still have several disadvantages such as excessive cost, difficulties in manufacturing and handling, instability of the zero level, etc. In this connection,

Compared with other photoelectric elements (various phototubes, photocells, secondary electron multipliers, phototransistors, etc.), the merits of this type of cell are the high power output (max. 1 w) and high sensitivity (far higher than any other types except the secondary electron multiplier).

For recording the changes of manometer head four different slender CdS cells, of 2.5, 5, 10 and 15 cm in length, were manufactured. The cell, connected to a battery, is placed parallel to and behind the mercury manometer so that the



A. ↓ : a single electric shock given to the left vago-sympathetic nerve. Time: 1 second.
B. —: repetitive stimulation of the splanchnic nerve. Time: 1 minute.

The authors have developed a simple and stable electromanometer utilizing the CdS photoconductive cell, and have found it to be really versatile for various purposes.

The photoconductive cell using a monocrystal of cadmium sulphide (CdS) has electric resistance amounting to more than $10^3 M\Omega$ in darkness, but being markedly reduced when exposed to light. Consequently, the current passed through the cell varies with the illumination, and yet the photoelectric current is proportional both to the intensity of the illumination and the applied d.c. voltage. A current of over 20 mA can easily be obtained by properly setting the intensity of illumination and the voltage applied. (For example, in a cell of 1 cm² area, the current was 3 mA for an applied voltage of 6 v and illumination of 100 lux, while it was 20 mA for 12 v and 100 lux.) The dark current is practically negligible within the limit of the applied voltage less than 50 v. The current increases with rise in temperature. In the range of temperature generally used (0–40° C), however, the rate of increase in resistance of the cell is approximately 7% per deg C.

light projected on the surface of the cell is screened by the column of mercury. The light source is an ordinary incandescent light used for microscopy. The change in pressure is converted to a change in photoelectric current. Sensitivity is increased by means of the connection of a Wheatstone bridge. When the hydraulic manometer is used, the machine oil, coloured deep with a suitable dye, e.g. Sudan Black, is placed on the water level for effective screening of light.

An example of the record obtained by this procedure is shown in the Figure. Records of the carotid arterial pressure of a toad are shown. The fall or rise in the pressure brought about by the stimulation of the vago-sympathetic or splanchnic nerve is clearly demonstrated.

In the electromanometer, in which the CdS cell is combined with the hydraulic or mercury manometer, the inertia of the fluid is naturally a limiting factor to rapid response, so that the manometer is not suitable for faithful recording of phenomena of high frequencies (e.g. the quick changes in the intraventricular pressure during one cardiac cycle).

Therefore the other types of electromanometer are not replaced with this. As shown in the figures, however, it is quite suitable for recording the phenomena with not very rapid fluctuation, particularly for stable and long-time recording.

The merits of the electromanometer utilizing the CdS cell are as follows:

- (1) The circuit is inexpensive and extremely simple. The manometer is easily handled.
- (2) A general storage battery can be used as the power source so that the manometer does not pick up any a.c. noise.
- (3) Its power output as well as sensitivity are so high that an amplifier is not required.

- (4) It is sufficiently stable to allow the continuous recording of pressure changes for a long time.
- (5) By properly selecting the medium of the manometer and the length of the CdS cell, the electromanometer can be fitted both for high tension (several hundred mm Hg) and low tension recordings (a few mm H₂O), and for a rather wide range of pressure from 1 to 300 mm.

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Monitors for diffractometer x-ray beams

The x-ray intensity monitor (Kiss and Patla 1961) is based on measuring the general scattered radiation from a thin aluminium foil kept in the path of the x-ray beam. It appeared interesting to compare the performance of this system with another (Chandrasekaran 1956, 1959) which was found useful in measuring the integrated intensities of single crystal reflection.

As the authors have themselves pointed out in their paper, the monitor measuring the general scattered radiation is unsuitable for indicating concurrent changes of the K_{α} component; only changes due to the current can be corrected by such a monitor. This is because any change in the voltage applied to the x-ray tube will affect the spectral distribution and the intensity of the general scattered radiation will alter in a complicated manner. This is a serious drawback where such voltage fluctuations occur during experimental periods since in most measurements, only the monochromatic component of the x-ray beam is of interest.

Fluctuations of the x-ray intensity due to voltage, current, or both, can be estimated correctly if a powder reflection from the aluminium foil is recorded by a monitoring counter. This method has been discussed by several authors (Peiser, Rooksby and Wilson 1960). In a particular series of measurements of the integrated intensities of various single crystal reflections, the 222 powder reflection from a thin aluminium foil was continuously utilized for monitoring. This reflection occurs at a Bragg angle of $\theta = 41^{\circ}$, for Cu K_{α} radiation and a collimator was suitably designed to receive a definite portion of the powder ring.

The loss of primary beam intensity, due to absorption by the foil was found to be about 32% but this was not serious and even weak reflections could be conveniently measured.

However, a difficulty arose in this system of monitoring. The integrated intensities of single crystal reflections are generally measured by rocking the crystal at a slow uniform

rate about the reflecting position and recording the total number of counts during this period by a Geiger counter set for the reflection. The ratio of this quantity to the count recorded by the monitoring counter during the same period was taken as a measure of the integrated intensity. This system was adequate only for slow, long-term changes of the beam intensity. This is because, for any rapid fluctuation in the x-ray intensity, the ratio will depend on the exact time at which the fluctuation occurred. A slight change of intensity at the peak of a Bragg reflection will affect the numerator of the ratio much more than the denominator and there is no way of finding from the two aggregate records of the Geiger counters, at what time instant of the integration period, the change occurred. There appeared to be no simple solution to this problem without recourse to an elaborate experimental set up and therefore in actual practice, each intensity measurement was determined as a result of four trials so that errors of this type were not serious. It was found that measurements of the intensities were reproducible to an accuracy of about $\pm 3\%$ over extended intervals of time, with an x-ray generator of the self-rectifying type having no automatic stabilizing features.

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New instruments, materials and tools

Pressure transducer type 4-309. Consolidated Electrodynamics Corp., 360 Sierra Madre Villa, Pasadena, California, U.S.A.

A new medium-to-high range pressure transducer described as the most accurate and sophisticated transducer ever built for airborne use utilizes a rated electrical excitation of 100 v d.c. or a.c. r.m.s. with a carrier frequency in the 100 kc/s range. Sensitivity is $50 \text{ mv} \pm 0.25 \text{ mv}$ measured against a $50 \text{ k}\Omega$ load at rated excitation and 70° F . Combined effects of non-linearity and hysteresis do not exceed $\pm 0.35\%$ sensitivity as measured from the best straight line through calibration data. Input impedance is 700 ohms minimum; output impedance is $350 \text{ ohms} \pm 10\%$ at 77° F . Self-contained compensation which permits precise electrical output simulation of pressure-generated output is featured. Environmental specifications include a compensated temperature range of $+30^\circ \text{ F}$ to $+250^\circ \text{ F}$ and an operable temperature range of -100° F to $+300^\circ \text{ F}$. Thermal zero shift is within 0.05% full scale per deg F and thermal sensitivity shift is 0.005% per deg F over the compensated temperature range. The instrument utilizes the unbonded strain gauge principle with a four-active-arm spring type sensing element and diaphragm force summing area. Designed as a chamber unit, the 4-329 is capable of performing absolute measurements of fluid compatible with type 416 stainless steel. External dimensions are approximately 1.125 in. diameter by 3.125 in. long including electrical receptacle, weight being 5.5 ounces maximum exclusive of mating electrical connector.

Frequency and time measuring equipment type TSA 3336. Venner Electronics Ltd., New Malden, Surrey.

This is a low priced instrument using transistor plug-in modules and a six-digit projection type in-line readout with automatic decimal point insertion. It provides for measurement of frequency up to 1.1 Mc/s with timing times of 0.1, 1.0 and 10 seconds, and an additional decade can be fitted to give 100 seconds. Accuracy ± 1 count $\pm$ crystal error which is maintained within ± 1 in 10^6 by temperature control. Input sensitivity is 0.5 to 50 v r.m.s. and input impedance about $250 \text{ k}\Omega$ shunted by 0.01 pF . Reciprocal frequency measurements can be made from 1 to 10^7 cycles of the applied frequency in decade steps, the upper limit for this facility being 1 Mc/s and accuracy $\pm 1 \mu\text{s} \pm$ crystal error. Time intervals from $1 \mu\text{s}$ to 10 s can also be measured, the input amplitude range in case being 6 to 200 v . Pulse outputs are available from a digital divider chain with an amplitude of about 5 v and mark/space ratio of 1:4. The instrument can be reset manually, by panel push-button, or by an automatic delay providing a display time of 0.5 to 5 seconds. It is suitable for either mains or battery operation, and can be fitted with facilities for direct operation of the Venner printer and reperforator units.

Digital volt ohm meter type TSA 3374. Venner Electronics Ltd., New Malden, Surrey.

The TSA 3374 digital volt ohm meter, which was developed in conjunction with Epsco Inc., Boston, U.S.A., employs a four-digit in-line, in-plane display covering 0.001 to 1100 v (d.c. and a.c.) and 1Ω to $1.1 \text{ M}\Omega$. Full-scale accuracy is to $0.1\% \pm \frac{1}{2}$ least significant digit on the d.c. ranges and to 0.25% on the resistance ranges. Accuracy on the a.c. ranges is a function of frequency and varies from 0.25% (50–200 c/s) to 3% (20–20 000 c/s). Sampling rate is 100 per second maximum on the d.c. voltage and resistance ranges, but is limited by the response of the indicators to 10 per second when reading, although the output signal is unaffected. The a.c. sampling rate is limited by the input signal frequency, the maximum available being 5 per second. Input impedance is $20000 \Omega/\text{v}$ except on the 1100 v range where it is $2.02 \text{ M}\Omega$. The instrument is of plug-in transistorized construction and employs no mechanical components subject to wear and tear such as relays or stepping switches. It can be connected directly to a Venner printer and/or reperforator, for the operation of which a print command pulse is provided at the completion of each conversion.

'Clam shell' arc imaging furnace. Arthur D. Little, Inc., Acorn Park, Cambridge 40, Mass., U.S.A.

Although furnaces using optically concentrated arc radiation have been commercially available for some years, the 'clam shell' furnace is claimed to offer a major improvement in efficiency. Losses due to shadowing are substantially reduced by locating both the radiant energy source and the specimen outside the reflecting system. The radiation enters the chamber through a circular opening in the back of one concave mirror and converges on the specimen behind an aperture in the back of another concave mirror. Temperatures in excess of 3500° K within an area 0.5 in. diameter are claimed. Potential applications which have been cited include the growth of rubies, sapphires, silicon carbide crystals, etc., and the welding of materials in any desired atmosphere (or vacuum) free from contamination.

Frequency counter converter. Hewlett-Packard Co., Palo Alto, California.

A previous converter enabled the accuracy, speed and convenience of a basic 10 Mc/s counter to be extended by several decades. An additional converter has now been developed that enables frequency measurements to be made from 100 Mc/s to above 500 Mc/s . A selected known harmonic of the counter's precision time base frequency is subtracted from the frequency being measured, leaving a difference frequency in the range from 0 to 10 Mc/s , which can therefore be measured by the counter itself. The sensitivity of the converter is constant over the full 100 – 500 Mc/s range, and is high enough (100 mV) to meet most laboratory and production frequency-measuring situations.

Notes and comments

Notes for the Preparation of Papers for the *Journal of Scientific Instruments*

The following instructions refer to the main points which have to be considered in the preparation of a paper for publication, and authors offering papers to the *Journal of Scientific Instruments* for publication are asked to conform to these recommendations.

Manuscripts

Manuscripts should be typed in *double* spacing on paper not wider than 8 in. and not longer than 13 in. Only one side of the paper should be used, and a margin of 1-1½ in. should be left. As alterations in the text cannot be allowed once the paper is set up in type, authors should aim at absolute clarity of meaning and of typing, and should check the typescript carefully before submission. All manuscripts should be submitted in duplicate, and in addition to the fair copies, a set of small copies or prints of the diagrams (not larger than foolscap) must be attached to each MS. (This enables MSS. to be sent to two referees at the same time and so assists rapid publication.)

Abstract. An abstract is printed at the beginning of the paper immediately after the title, name(s) of author(s), and place of employment of author(s). Two extra copies of the 'title and abstract' page are required for the records.

Mathematics. It is not necessary to give detailed derivations of mathematical expressions and formulae in a published paper when the work is straightforward; it is quite sufficient to indicate the method of treatment and the final results.

References. In the text bibliographical references are made by giving the name of the author and the year of publication in brackets, e.g. (Jones 1942), and details are given in the last section, 'References', where the references are arranged in alphabetical order of authors' names and in date order for each author.

Drawings

Drawings should be in Indian ink on tracing cloth, tracing paper or white card, with lettering in soft or blue pencil; lettering of a size suitable for reduction will be inserted by our draughtsman. The drawings should in general be sufficiently large to allow of reduction in printing, and the lines should therefore be bold; the frame lines of graphs should be slightly finer than those of the plotted curves.

Full details are available in the Institute and Society's

'Notes for Authors'; obtainable from the Editor and Deputy Secretary, The Institute of Physics and The Physical Society, 1 Lowther Gardens, Prince Consort Road, London S.W.7.

Papers for publication in the *Journal of Scientific Instruments* should be sent to the Editor and Deputy Secretary at the same address.

Letters to the Editor

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British Journal of Applied Physics

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NOTES AND NEWS

New books Notes and comments

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Conference on Optical Instruments and Techniques—London 14th July 1961

THE Conference on Optical Instruments and Techniques, arranged by the British National Committee for Optics, was the sixth conference, which has been held since under the auspices of the International Commission for Optics. The representation of 22 countries by about 300 delegates, and the scientific content and diversity of the six sessions, were an adequate answer to any who feel that the future of optics is one of diminishing opportunity. At the last conference on optical instruments held in London in 1950 the principal topics were phase contrast microscopy, interference microscopy, diffraction and the production of diffraction gratings. In the eleven years since then the application of optical techniques has spread very actively into many new fields, and in doing so, is demanding more and more the application of mathematical and technical resources. It seems clear from the part of the conference devoted to the design of optical systems that the technique of designing optical systems may change in the next few years by the application of large digital machine methods. It is equally likely that blind searching for optimum designs with computers is unlikely to be very fruitful, because of the number of variable parameters in a relatively simple optical system. Whilst machine methods have in some cases succeeded in making marginal improvements only to existing systems, the 'feel' by means of which earlier workers were so successful in design problems will be replaced by a 'feel' for computer methods, perhaps with the remoulding of aberration theory and the application of response function techniques. The need for intellectual and optical experience in the approach to computer techniques was emphasized by one speaker who said that he now found it difficult to see how Taylor had ever succeeded in finding such a good triplet. A second session was concerned with optical systems associated with the American and Soviet rocket and satellite programmes. The group of papers presented were on topics varying from essentially simple light-borne cameras used at the Woomera range, to extremely compact devices for ultra-violet stellar spectrometry from rockets, and ones for aiming and tracking space vehicles by laser and infra-red systems. Here, as in other growing branches of technology, optical and electronic components are complementary to one another. Considerable ingenuity has often been a feature of optical instruments, and workers without access to, or funds for, expensive machinery could well take heart from several elegant devices which were described during the conference, some employing old established principles in extremely novel ways with a minimum of costly equipment. In one case a problem which began as the rather difficult electronic one of storing and printing in a random way 10 000 letters or diagrams, was solved by an optical tunnel employing the principle of the endoscope, to make any point on a field of view appear at any location. In another paper, in a disarmingly simple and entertaining way, the speaker described methods of using flat and spherical surfaces in conjunction with Airy's rings or rainbows to test accurately the straightness and lengths of distances up to 20 metres. A third paper had the intriguing title of 'Mock Interferometry'.

In the Presidential address Professor Inglestad touched on some of the human factors which operate in research and underlined the need for leaders of groups to allow students to take part in worthwhile research, and to be named in publication of the results. He stressed the need for extension of the international exchange of research workers, under the auspices of the International Commission for Optics, and saw no bar to this in the different approach to research in different countries. It seems to the writer of this report that some of the correct spirit must always exist in optical research while there remain people who approach their work as one speaker has done. At the end of his paper he said he did not know if his work would prove to be of any practical importance, but he has 'enjoyed playing with these beautiful colours'.

An exciting part of the conference provided many members of the audience with a first opportunity of seeing and hearing about one of the newest optical developments, that of optical masers. Two ruby masers were shown in action sending light on to a screen, and the existence of spatial coherence over small regions of the rod was demonstrated by placing two slits in contact with the end and projecting interference fringes. It is clear that these active rather than passive optical elements must play an important part in optical instruments, providing as they do for the first time the possibility of amplifying light.

It has been clear for some time that the use of accurate aspheric surfaces in optical instruments is unlikely to be extensive until fast and cheap methods of producing and testing them are invented, and there will perhaps be little impetus to the design of aspheric systems until such techniques are available. There were a few welcome approaches to the problem in papers presented to the conference.

The general arrangements for the conference were extremely well conceived. In the organization it is a difficult problem to judge what will be a reasonable time for the presentation and discussion of each paper. Usually 25 minutes is too short for a paper creating considerable interest and discussion, sometimes it is too long. It is difficult to hold any useful discussion in 5 minutes, and it may be more profitable to collect papers on closely allied topics into small groups, allowing reasonable time for discussion at the end of each group. With the firm but kindly chairmanship of the sessions a frequency of seven papers per morning was not excessive, except when a speaker assumed either that the audience had not read the abstract provided beforehand, or that it had already read his as yet unpublished paper.

The intention in this short report has been to present some general impressions of the conference, and in some cases it will be clear that the selection of material for the report indicates personal preferences by the writer. There will be a better opportunity for detailed understanding of the papers presented when the proceedings of the conference are published in full by Chapman and Hall Ltd.

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W. J. BATES

Colloquium on Optical Materials—Paris 1961

THE Colloquium on Optical Materials was held in Paris from July 5th to 8th; it was organized by the Comité Français d'Optique for the International Commission for Optics.

After addresses by Professor Fleury, Director General of the Institut d'Optique, and Professor Ingelstam, the President of the International Commission for Optics, the first day's subject was introduced by A. Smakula with a survey on synthetic crystals and polarizing materials. As a solid state physicist, Smakula dealt with the essential structural characteristics (electronic, atomic and molecular) of synthetic crystals from the point of view of their use as optical materials, filters, x-ray monochromators, infra-red detectors, masers, scintillators and polarizers. There followed four papers on the preparation of synthetic crystals: by J. Koerber on the history of synthetic monocrystals in France since 1945, A. C. Walker on the development of the high pressure autoclave method for growing quartz crystals for oscillators, J. Schapelle on the growth of sodium nitrate crystals from saturated solution and E. M. Gillis on an improved Verneuil apparatus for preparing boules of metallic oxides such as corundum and sapphire. Single crystal boules can now be produced in lengths up to 6 cm with a diameter of 0.8 cm.

An up to date account of crystals and polarizing materials available for optical components was given by S. S. Ballard. The growing importance of instrumentation in the near and intermediate infra-red regions, supported by improvements in infra-red detectors, has stimulated the development of new infra-red optical materials, especially those having good mechanical and thermal properties. Among the new materials mentioned were the Eastman-Kodak materials Irtran I and Irtran II. Irtran I is hard, has a low refractive index (1.34) and is transparent to 6μ ; Irtran II covers the range 2–14 μ but has a high refractive index. For polarizing infra-red radiation silver chloride plates must be used in the intermediate region but Polaroid HR is available for the range 0.8–2.0 μ . This session included two papers by J. W. Gates on the transmission factor of synthetic crystalline quartz in the far ultra-violet and the measurement of refractive index of ultra-violet transmitting materials. W. Wolfe discussed the advantages of semiconductors as optical materials in the infra-red and mentioned the value of binary and ternary semiconductor alloys as short-wave cut-off filters: for instance the system GaAs–GaInAs–InAs covers a continuous range from 1 μ to 4 μ . E. Käsemann gave the only paper devoted to the properties of polarizing film.

Y. Peyches opened the session on glassy materials with a discussion of modern theories of the structure of glass. Examination of glasses by x-ray diffraction and by infra-red and Raman spectroscopy only yields information on the structure of the elementary silicon-oxygen tetrahedra and their local bonds. The linking of these units into an extended structure representative of the glassy state and compatible with its known properties becomes a somewhat arbitrary procedure. Another way of describing the glassy state is to imagine it as an organized structure made up of the units of which the existence has already been established but containing a large number of crystallographic faults which can exist without bringing about the collapse of the structure. It is significant that glass-forming oxides often do not have a sharp melting

point even in their crystalline form; the glasses which the oxides form may have such 'loose' structures that the disorder created by heating to a temperature in the melting region is tolerable. In oxide glasses the cation is the more easily displaced and can find a new metastable position: the ratio of volume of lattice vacancies to volume of cations should therefore be a measure of the likelihood of a glassy state. In fact a classification of oxides on this basis does result in the correct ordering of oxides as glass formers and modifiers.

A second theoretical paper on the properties of glasses in this case the electronic structure giving rise to optical absorption, was given by Mme A. Winter. She showed that the *d*-electron energy level for metals of which the oxides give rise to selective absorption is sub-divided into two or more levels in the oxide; transitions between these sub-levels account for absorption bands in the visible spectrum. This hypothesis is confirmed by calculation of the difference in energy levels, based on the parameters of the internal electric field.

The technology of glassy materials was represented by papers on advances in the production of fused silica and telescope mirrors with skeletonized supports (H. Mohr), the preparation of germanium oxide, germanium sulphide and lithium fluoride infra-red windows (S. Nielsen), and the action of α -rays of high flux density on the structure of Pyrex, lead and soda glasses (M. J. Paymal). The transparency of the Heraeus fused silica has been improved in the ultra-violet and in the infra-red so that the glass named 'Suprasil' transmits from 1700 Å to 4 μ , the OH band at 2.7 μ having been greatly reduced in intensity; this glass also resists discoloration under irradiation by gamma rays.

For a study of the more practical aspects of glass technology delegates enjoyed the hospitality of the St. Gobain Glass Company. After lunch at the administrative headquarters, a discourse was given by M. H. Meyer on the introduction of modern methods of optical glass manufacture leading to improvements in their quality (e.g. an EDF glass with high transparency out to 5 μ). The visit ended with an extensive tour of the laboratories of the Company; some very interesting methods for the examination of 'industrial' glass were noted, including a multiple-flash camera for high-speed photography of fracturing glass plates, a multi-channel recording emission spectrograph for glass analysis and a high resolution (8 Å) electron microscope of Japanese manufacture.

A whole day was given to recent work in the realm of thin films. A review by O. S. Heavens of advances in the preparation and applications of thin metallic and dielectric films with particular reference to the ultra-violet and infra-red region was followed by 14 papers on structure, optical properties, and practical uses. It was interesting to hear from H. Schroeder that the method of deposition from solutions of metallic and organic compounds, once used fairly widely in Germany for anti-reflection film coating, has been revived for the deposition of mixed compounds; thus, metal oxides mixed with silica form neutral or coloured absorbing films of low refractive index, avoiding the disadvantage of high reflectance associated with the absorbing oxide deposited on its own.

The Marseilles school under Professor Rouard and

but d'Optique of Paris continue their meticulous study of the structure of thin films; by good control of the variables of the deposition process, characteristic effects such as surface layers at the boundaries (M. Bourg) and variations in the organization of the crystallites (J. R. Gonella and B. Rieus, Mme M. Gandais, and P. Croce) can be examined systematically. F. Abelès carried the development of the study of metal films further with a correlation of optical and electrical properties of gold and gold alloy films.

It is impossible in this summary to do justice to all the papers in this section owing to their very wide range of subjects, e.g. films of silicon oxide and lead oxide, films in the ultraviolet, films of adjustable refractive index, diffraction gratings, thin films, and the structure of surface layers produced by etching glass (in which K. Kinoshita shows that the skeletal structure absorbs water vapour to an extent depending on atmospheric humidity).

The final session dealt with techniques for the examination of glass. M. Françon gave a concise account of the many methods of examining inhomogeneity of glass. These were classified under three headings: interferometry and phase contrast, strioscopy, examination of image of point source. Some of these methods were described in detail in later papers (A. Maréchal, G. Nomarski).

The effect of inhomogeneities in optical glass, a practical subject of great importance in the production of high class components, was investigated by A. Arnulf. Particular attention was paid to tolerances for the refractive index and internal stresses; Professor Arnulf pointed out that in making a glass surface to a very accurate figure the relaxation of internal stresses could cause the figure to change in an

unpredictable manner. In the discussion of this paper A. Cox emphasized the importance of stress-free glass for commercial lens production—distortion of the surface by relaxation of internal stress during high speed polishing can result in a serious proportion of rejected lenses. The need for homogeneous glass and the difficulty of manufacturing and annealing it are accentuated when the components become really massive as in the wind tunnel windows described by C. Veret, who dealt with the methods used for examining the quality of plates 105 mm thick.

The difficult problem of measuring the degree of polish of the surface was attacked in only one paper, by A. Maréchal, though P. Bousquet investigated the measurement of surface irregularities (in films of aggregated structure) too small to cause any observable diffusion.

Finally must be mentioned the demonstration by G. Novaski and Mme G. Pigeat of the possibilities of the little-used technique for surface examination by means of replicas for the optical microscope. Some striking pictures in colour of surface structures such as growth spirals on silicon were shown, the colour being produced by interference contrast.

It is not intended to publish the proceedings of this colloquium in book form but authors have been invited to submit their papers for publication in *Optica Acta*.

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Instrument for the measurement of elastic hysteresis in torsion

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Abstract

The paper describes an instrument capable of measuring the elastic hysteresis of a rod specimen in torsion under static conditions, when the hysteresis strain is only a few parts in 10^4 of the maximum strain. An interferometric strain gauge is employed with specimens approximately 9 in. long $\times \frac{1}{8}$ in. diameter.

Introduction

THE stress-strain curves of an elastic material taken during loading and unloading may not exactly coincide, even though the elastic limit is not exceeded. The effect is known as elastic hysteresis and may be particularly marked among magnetostrictive ferromagnetics, the material being in differing magnetic conditions during loading and unloading.

Energy is dissipated when such a material is cyclicly stressed and it is through the damping capacity of such materials that most previous studies have been made (see for example Sumner and Entwistle 1958, 1959, Cochardt 1956, Kolsky 1953). The instrument described in the present paper, however, is concerned entirely with static measurements of the hysteresis loop.

This equipment was required particularly for measurements of mechanical hysteresis in magnetic alloys used in the manufacture of weighing machine springs. These alloys possess zero variation of Young's modulus with temperature and must also possess a mechanical hysteresis less than about 0.02% of the maximum strain during loading.

Figure 1 is a schematic stress-strain diagram for a material showing elastic hysteresis. If the applied stress is cycled between positive and negative values, the loop is open at the origin. However, if the stress is cycled between zero and some positive value, a minor loop such as K B C E A D K is obtained. For many purposes the loop is adequately described by the single parameter h , which is defined as the width of a loop measured parallel to either axis divided by the total length of the loop projected on to the same axis. Thus, in terms of strain

$$h_1 = \frac{KN}{GS} \text{ for the major loop} \quad (1)$$

$$h_2 = \frac{AB}{GK} \text{ for the minor loop.} \quad (2)$$

The choice of parameter h_1 or h_2 depends on the application for which such springs are intended.

The apparatus described in this paper enables h to be determined for specimens in torsion when this is the order of 10^{-4} .

In order to measure AB/GK two requirements must be met:

(i) A means must be provided for applying an exact reproducible stress so that AH may be made equal to L

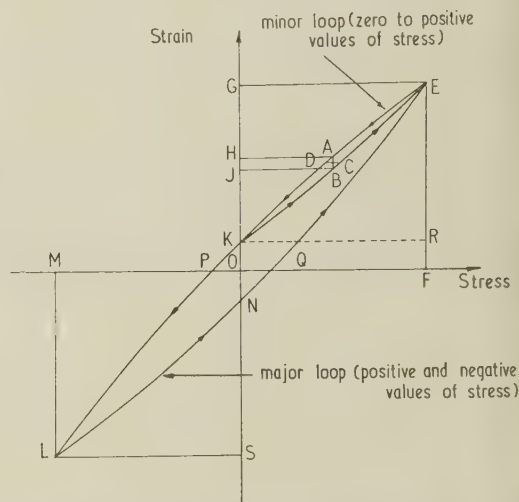


Fig. 1. Schematic stress-strain curve for a material showing elastic hysteresis.

The absolute value of the stress BJ is not critical since the width of the loop changes only slowly along its length. The couple is therefore applied to the specimen by means of balance beams and weights using knife edge pivots, as in a chemical balance.

(ii) Two strain gauges must be provided; the first to measure the total strain GK, and a second to measure the residual strain, AB directly, without reference to the overall strain. The first strain gauge is a conventional optical lever and the second a modified Michelson interferometer with the terminal mirrors mounted on the specimen in such a way that the wedge fringes appearing in the interferometer give a direct measure of the small angular strain AB. The interferometer also includes two mirrors which may be rotated by micrometers to obtain a fringe-free field of view and the apparatus is in fact used as a null instrument with the corresponding readings being taken from the micrometers.

The procedure for plotting the minor loop is as follows. After noting the original strain condition with the optical lever, a load representing the stress JB is applied and the interferometer is adjusted to give a fringe-free field. The stress is then increased to equal GE, the strain ER being noted on the optical lever. The load is thereafter returned

former value, when the alteration in the micrometer readings required to regain the fringe-free condition gives a measure of the strain ΔB .

Some details of principle and construction

(i) Mechanical

The sample is clamped between two balance beams, each of which is critically balanced (i.e. infinite period of free oscillation). The couple is then applied to one beam whilst the other beam is used as a rotatable clamp to maintain the loading beam horizontal. The mirror assembly, attached to the specimen, introduces a small but constant uncertainty (about 0.1%) in the absolute value of the applied couple.

The couple Q applied to the specimen, by a mass m is given by $mgL \cos \beta$, where L is the half length of the loading beam and β is the inclination of the beam to the horizontal. It follows that for a given load

$$\frac{\delta Q}{Q} = -\tan \beta \delta \beta. \quad (3)$$

if the couples applied at the half load position, before and after full loading, are not to differ by more than one part in 10^5 , the angular position of the loading beam must not change by more than $\delta \beta$ given by

$$\delta \beta \approx \frac{10^{-5}}{\beta} \text{ radians} = \frac{3.3 \times 10^{-2}}{\beta} \text{ degrees.} \quad (4)$$

if the beam is one degree away from the horizontal during loading it should be within two minutes of arc of the horizontal position during unloading. This requirement is readily satisfied by clamping one end of the specimen and by rotating the other clamped end to bring β as near as possible to zero at the

This is achieved by attaching to each end of the specimen an end piece consisting of an incomplete sphere, which is a

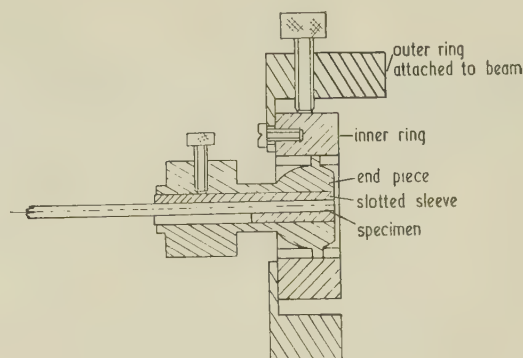


Fig. 2. Specimen clamp.

sliding fit in a cylinder attached to the beam. This cylinder may be accurately adjusted and clamped so that its axis is co-linear with the central knife edge pivot, thus assuring that the mid-point of the end of the specimen is on the axis of rotation of the beam. The couple is transmitted by a peg through the spherical end piece, which is received by slots cut on the inside of the cylinder, parallel to its axis.

The problem of damping unwanted oscillations about the equilibrium position is particularly acute, partly because of the small angular strain which is to be detected, and partly because the energy to be dissipated from an oscillation of given amplitude is far greater than in the case of a chemical balance, since the restoring force in this case is provided by the specimen. Magnetic damping using aluminium sheets

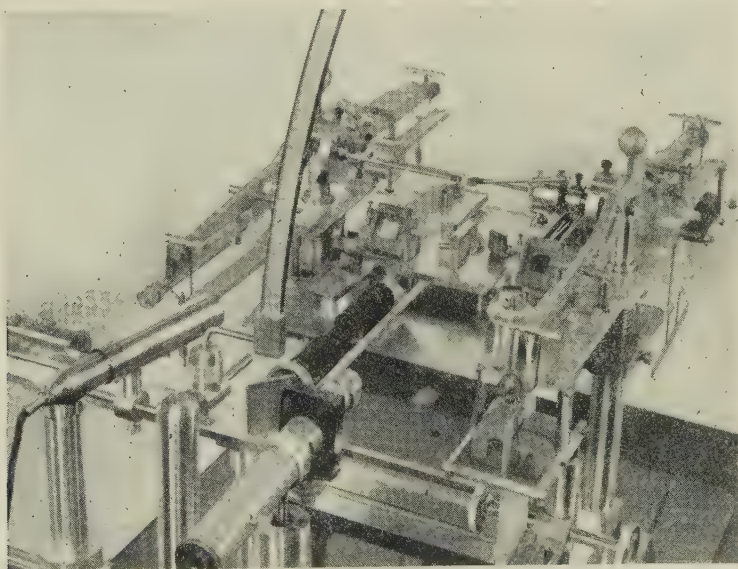


Fig. 3. General view of the instrument showing the curved scale of the optical lever, the magnetic damping arrangement, and the interferometer.

load position. Provided the elastic hysteresis effect is the only contributor to $\delta \beta$ the above condition is normally satisfied.

In order that the loading beam shall pivot perfectly on its central knife edge, it is necessary to transmit the couple to the specimen through a well-centred universal joint (Fig. 2).

suspended from the ends of the loading beam between permanent magnets, was found to be satisfactory. Care has been taken to arrange the magnets symmetrically and to eliminate all magnetic materials from the moving parts of the equipment so that no unwanted couples can arise from the presence of the magnets. The arrangement of the magnets

is visible in Fig. 3. Calculation showed that conventional air damping could not provide a satisfactory alternative to the magnetic method.

(ii) Optical

Figure 4 shows schematically the arrangement of mirrors employed in the interferometer. Green light filtered from a low pressure mercury vapour lamp is incident upon the mirror F which reflects it on to the half-aluminized mirror C. The mirrors A and B are the terminal mirrors mounted on the

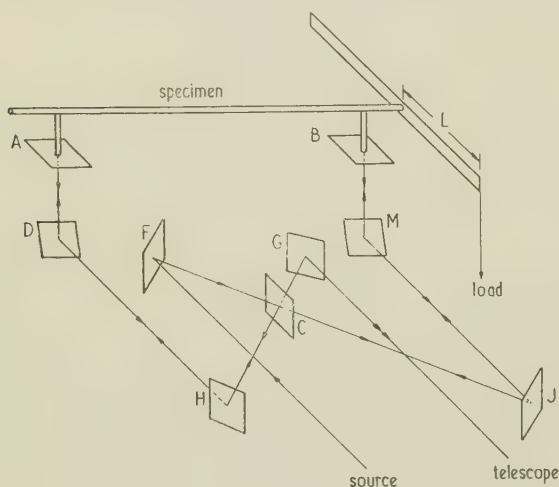


Fig. 4. Schematic diagram of the mirror system and light paths in the interferometer.

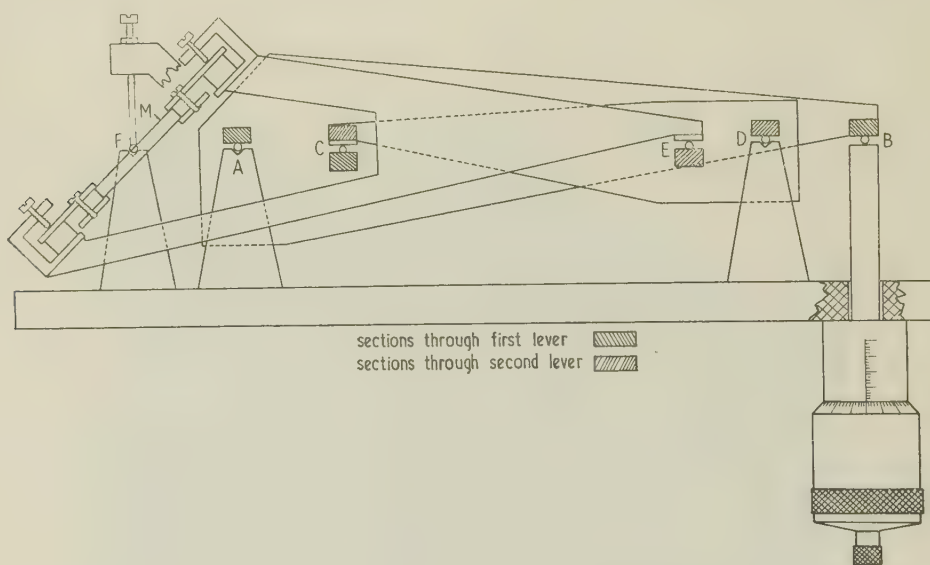


Fig. 5. The reduction lever system to control the mirror M of Fig. 4. For explanation see text. (Not to scale.)

specimen, and the paths CHDADHC and CJMBMJC are equivalent to the two limbs in the usual Michelson arrangement. Light from the mirror G enters a telescope which is focused on the surfaces of A and B. All the mirrors except F and G are flat to a tolerance of $\frac{1}{10}\lambda$. The two mirrors D and M may be rotated about an axis parallel to the specimen

by micrometer screws, so as to offset any angular difference between the positions of the mirrors A and B. A one hundredth of the linear motion of one micrometer transmitted by a compound reduction lever to the end of an arm mounted on the back of the mirror M. The lever system was designed to eliminate backlash in the transmission of micrometer movement to the mirror. The arrangement is illustrated in Fig. 5 and consists of three levers. The first of these is supported on the fulcrum A and the micrometer spindle B. The pivot at A consists of two $\frac{1}{16}$ in. ball bearings cemented to the lever and resting in a groove in the support member. As the lever moves they rotate about their line centres by slipping at their points of contact. At B there is also a sliding ball contact, the ball being cemented to the lever, and arranged so that it bears on the rotating surface of the micrometer spindle well off-centre in a direction perpendicular to the length of the lever, thus eliminating any lateral dragging of B as the spindle rotates. A ball bearing is cemented to the first lever at C and makes sliding contact with a glass flat on the second lever. Similarly, the second lever is pivoted at D and carries the end of the third lever at E. By arranging for the centres of the balls at A and the point of contact at C and B to be coplanar, and likewise the centres of the balls at D and the points of contact at C and E, a linear relationship between the vertical positions of B and of E may be made perfectly linear, even for large movements of the micrometer spindle. The third lever is pivoted at F, again on balls slipping in a groove, and carries the mirror M in a double frame arrangement which may be adjusted to bring the axis of rotation through F accurately into the plane of the mirror.

The mirror D of Fig. 4 is also micrometer driven without the reduction levers, and thus has a calibration

constant about 100 times larger than does the mirror M. is used in the initial setting up of the interferometer.

A remote control on the front of the instrument enables the micrometers to be adjusted without risk of disturbing the instrument.

The terminal mirrors and also the optical lever mirror

mounted on the specimen by means of a bushing which covers the specimen with about 0.005 in. clearance. The bushing contains three sharp pins of tungsten carbide, spaced at 120° to each other, which are screw-driven into the specimen and subsequently clamped. Just sufficient force is applied to leave a slight visible indentation in the specimen. These pins are the only points of contact between the mirrors and the specimen and thus provide a well defined contact length which may subsequently be measured with a scanning microscope.

Calibration and results

To calibrate the interferometer, a rigid dummy specimen was used to provide fixed terminal mirrors (A and B of Fig. 4), the telescope, which contains a graticule scale in the eyepiece, was focused on their surfaces. A graph was then plotted of the number of fringes per graticule division against micrometer setting. One of the terminal mirrors was then replaced by a new hacksaw blade having exactly 32 teeth per inch, and illuminated in silhouette, and this was used to determine the overall magnification of the telescope, so that previous readings of the numbers of fringes per division could be reduced to a number of fringes per centimetre on the surfaces of the mirrors.

This calibration determined that a movement of 0.001 in. on the micrometer was equivalent to an angular twist of the specimen of 2.950×10^{-4} deg. It also revealed no slipping or backlash in the action of the reduction levers, the micrometer settings for the null point (fringe-free field) being reproducible to ± 0.002 in. or 0.003 in. Thus an angular change in the twist of the specimen (corresponding to AB in Fig. 1) of 10^{-3} deg can be detected.

Figure 6 shows an example of the results obtained by means of this instrument on a commercial alloy used in the production of weighing-machine springs. The straight line is the direct stress-strain graph, and the two curved lines represent the width of the loops in Fig. 1 as a function of stress for a minor and a major loop having a maximum stress of 18×10^8 dyn cm⁻².

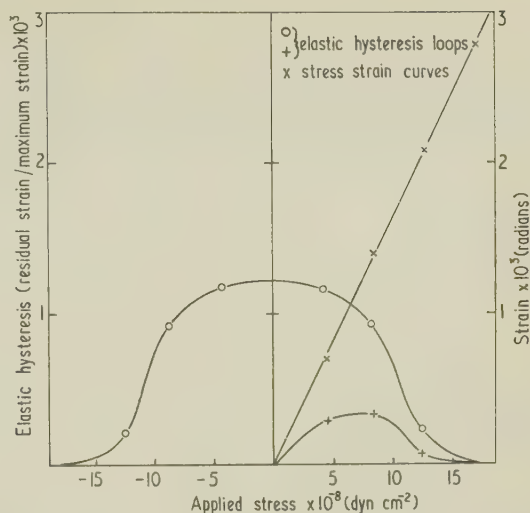


Fig. 6. An example of the results obtained. The curved lines represent the width of the hysteresis loop as a function of applied stress for a major and a minor loop. The quantities h_1 and h_2 as defined in Eqns (1) and (2) are 0.00125 and 0.00034 respectively. The straight line is the direct stress-strain relationship, from which the torsional modulus may be determined.

Acknowledgments

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Analogue computer for the summation of Fourier series with digital recording of the results

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Abstract

An a.c. analogue computing machine is described, which carries out the summation of the Fourier series

$$\sum_{h=0}^H A_h \cos 2\pi hx + \sum_{h=0}^H B_h \sin 2\pi hx$$

with $H_{\max} = 40$ for every third degree. The calculation is performed by a method in principle given by Hägg and Laurent. Voltages from an autotransformer, proportional to the trigonometric functions, are connected to decade potentiometers, introducing the coefficients via rotary switches. From these potentiometers small currents are fed to a common impedance, and the voltage over this gives the sum of the Fourier series. The result is converted to digital form by means of a relay system and printed automatically. The time necessary for one summation is 3 seconds. An example showing the accuracy is given.

Introduction

DURING the last ten years an extensive development of digital computers has taken place. The stage has now been reached where all calculations in a crystal structure determination can be performed on such machines. In spite of this there has been considerable interest in analogue machines for the summation of Fourier series because they are cheap and are therefore available in the crystallography laboratory. Their lower accuracy and speed are not considered to be too big a limitation for the first stage of a structure determination. The development has followed two lines: mechanical analogue machines (Hoppe and Pannke 1956, Timbrell 1958) and electrical analogue types. The electrical machines are either of the a.c. type (Braun 1956, Frank 1957, Hägg and Laurent 1946, Ramsey, Lipson and Rogers 1952) or of the d.c. type (Rymer and Butler 1944, Weber 1958). In this paper an a.c. machine with current summation is described. The essentially new feature of this machine is the presentation of the results in digital form.

Principle of calculation

The machine is designed to sum the series

$$\sum_{h=0}^H A_h \cos 2\pi hx + \sum_{h=0}^H B_h \sin 2\pi hx$$

with $H_{\max} = 40$, and to perform the summation for every third or every sixth degree as required. The summation principle is the same as that described by Hägg and Laurent (1946). Voltages proportional to the values of the sine and cosine functions for every third degree are tapped from an autotransformer. They are coupled via electro-mechanical

rotary switches (LM Ericsson type RVF 16) to voltage dividers of the decade type, which perform the multiplication with the coefficients A_h and B_h . Small currents from the voltage dividers are fed to a sign determining unit consisting of a difference amplifier. The output from this difference amplifier is the required sum, and after a three-stage amplification this is fed to the analogue-to-digit converter part of the machine.

This conversion is performed in the following way. After rectification, the unknown summation voltage is compared stepwise with a rectified reference voltage V_r from a Thomson Varley potentiometer. Initially, the range is determined by the relay switch S1 in the C position (Fig. 1). Then S1 is switched to the D position and these contacts begin a stepwise advance. When the polarity of the difference V between summation voltage and reference voltage changes.

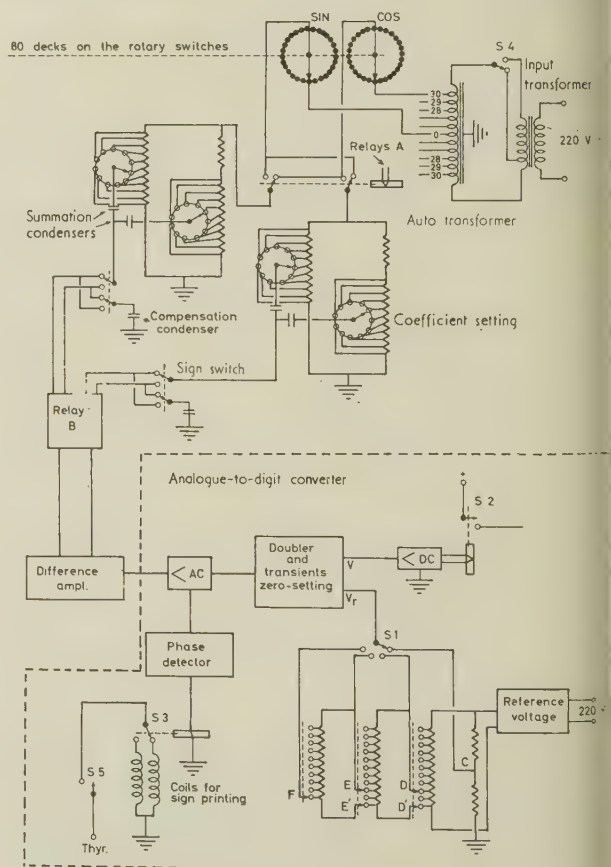


Fig. 1. Principal scheme of the machine.

or relay S2 halts the progress of the contacts D-D'. The position of these contacts now indicates the first digit of result. Afterwards S1 is switched over to the E-E' contacts, and the balancing of the E-E' contacts gives the second digit, and so on. The result is quoted with three digits and its sign is determined by a phase detector. This relay is connected to the three stage a.c. amplifier via a relay S3, and controls the sign by means of the relay S3.

Building up of the harmonics

The auto-transformer consists of a toroid of mumetal with 1000 turns of thick copper wire in two layers. In this way the ohmic and core losses and leakage are kept so low that the stability of the voltages from the transformer under a changing load is better than 0.2%. The number of turns is a compromise between the need for voltage stability under a changing load and the accuracy of the voltage measurements. The auto-transformer is fed by a step-down transformer (6:1) from the mains. Initially it was thought probable that the summation currents should have a frequency different from that of the mains, to avoid interference with stray currents outside the machine. However, this proved unnecessary for the level of accuracy at which the machine is operated.

The rotary switches have 30 steps and build up the harmonics only from 0° to 90°. The interval 90° to 360° is covered in the following way. For odd wave numbers the sine and cosine decks are interchanged at every 90 degrees with the aid of the relays A (Fig. 1). In addition, the signs are changed at 180° and 360° for wave numbers of the form $4n + 1$ and at 90° and 270° for $4n + 3$ (relays B, Fig. 1). For even wave numbers it is only necessary to change the signs for $4n + 2$ at 90°, 180°, 270° and 360°. The relays controlling these deck and sign changes are actuated by a stepping relay counter which is stepped by the rotary switches every whole revolution. In this way it has been possible to build up all harmonics with only 80 decks (16 rotary switches). It has been found very useful to reserve one deck for each switch for the purpose of checking that all the rotary switches step in phase.

Following the rotary switches, the summation current flows through the amplitude potentiometers. Each potentiometer consists of two decade resistors in parallel followed in series by a summation capacitor (750 pF mica). The decade resistors are made up of banks of ten wire-wound resistors with a tolerance of 0.1%. To avoid overloading the transformer, the impedance of each bank is limited to 10 kΩ. The summation capacitor ensures that the maximum current drawn from the bank of resistors without disturbing the stability of the potentiometer. The maximum non-linearity is 0.5% at 50 c/s.

The potentiometer is incorporated into a compact, easily adjustable unit with the summation capacitors, a sign switch and a compensation capacitor. This last component prevents the position of the sign switch influencing the two input voltages to the difference amplifier.

Conversion from a.c. to printed decimal digits

The difference amplifier, the minus and plus terms are added separately at the two inputs and these sums are then rectified. The amplifier has two triodes with a common mode circuit incorporating a constant current device to prevent the common mode effect (Valley and Wallman 1948). The difference is amplified in a linear three-stage amplifier, with a high negative feedback (loop gain 100) which gives

it good stability and a high degree of linearity. The output is rectified in a doubler consisting of semiconductor diodes to avoid any filament drift. Such a device has the disadvantage of a small voltage nonlinearity, but this has been allowed for in the resistances of the first decade corresponding to digit 100 (or 1000 in the higher range). The d.c. voltage obtained in this way deviates from the input d.c. voltage by less than 0.1% for sums in the range 100–10000 and about 1% for sums between 50 and 100.

The movement of the comparison point in the Thomson–Varley potentiometer is actuated by relays. Of these there are three series of ten relays each, corresponding to the three decimal digits. These relays unlock consecutively when the machine is measuring a sum. Every one of these relays has contacts for three different functions: (i) two contacts corresponding to D-D' in Fig. 1, (ii) two contacts to perform a rapid movement of D-D', (iii) one contact to connect the energy supply to the coil of the digit corresponding to the balance position of D-D'. In this way the relay also has a memory function, namely to store the digit until the moment of printing. In order to obtain a high measuring speed, the release action of the relays is used to effect the stepping motion of the contacts. In the Thomson–Varley potentiometer the time interval between two consecutive relay releases has been chosen so that it is 100% longer than the time required for the relay contacts to come to rest. For all the other relays 50% has been found sufficient.

The difference V between the voltage to be measured and the reference voltage is amplified and used to control a sensitive polarized relay which stops the progressive unlocking of the ten relays as soon as the polarity has changed. The amplifier used is a d.c. two-stage symmetrical differential amplifier, chosen because of its inherently good cancellation of the drift arising from variations in heater and supply voltages (Valley and Wallman 1948). The presence of the constant-current valve in the cathode circuit and the operation of the amplifier at a working point close to cut-off give a high input impedance at the first stage even for positive input voltage. In this way overloading of the doubler through transients during balancing of the potentiometer is avoided. 30% of the voltage of the last digit unit is sufficient to energize the relay for 2 ms.

A special voltage stabilization is not necessary since both the a.c. voltage of the sum and the voltage that feeds the potentiometer are proportional to the mains voltage. However, care must be taken to make the time constant for the rectifier of the reference voltage equal to that for the doubler. When this is not the case, a fluctuation of about 1% between V and ground (Fig. 1) has been found at balance. The cause of this fluctuation is bad tracking between the summation and reference voltages, arising from a fluctuation of mains harmonics. Since the amplitudes and phases of the harmonics of the summation voltage are changed through differentiation, the mains feeding the reference voltage must be differentiated to the same amount. After making proper correction for this effect the tracking has been found to be better than 0.1%.

The doubler is followed by a two-stage filter with time constants of 80 ms for increasing and 560 ms for decreasing signals (Fig. 2). Thus a time of 3 s is required for decreasing signals to reach a value, deviating not more than 0.1% from the new stationary value arising from a change of summation voltage. For the purpose of shortening this time a set of contacts is provided, with the aim of discharging the capacitors and limiting the doubler transients to 360 ms. The zero-setting is performed in three steps. First, all three

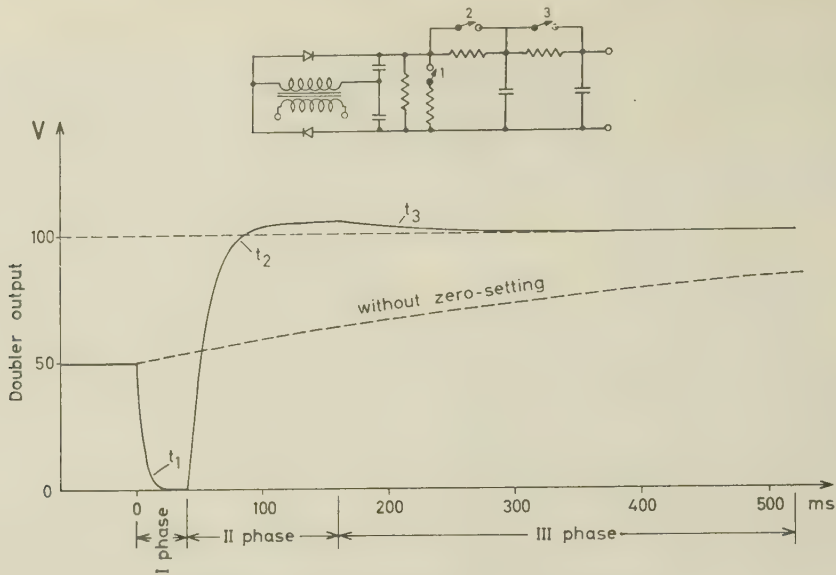


Fig. 2. Doubler transients during zero-setting.

contacts close and the capacitors discharge rapidly ($t_1 = 5$ ms) during 40 ms. The second phase starts with the opening of contact 1. The capacitors now charge rapidly ($t_2 = 15$ ms) during 120 ms. The opening of contacts 2 and 3 initiates the third phase. The voltage decreases ($t_3 = 60$ ms) slightly because of the reduction of the doubler capacity. The zero-setting is carried out twice during every working cycle namely at the beginning and at the end of the cycle.

The printing of the results is carried out by electro-magnets mounted on an ordinary commercial adding machine, using a broad roller for the paper (Addo-X). A thyatron circuit is used to excite the electromagnets and also the filter zero-setting described above. Starting impulses for the thyatron are supplied at predetermined times by control relays, which are described below. These pulses are or-coupled at the input of the thyatron. The control relays also determine whether the zero-setting coil or the digit coils are connected in the anode circuit of the thyatron.

The timing of the various operations (range-finding, zero-setting etc.) is made by 32 consecutively working control relays. The opening of one relay causes the next one to operate after a time fixed by the delay of the preceding one. This time is always chosen to permit the completion of a particular operation. The sequence of operations is given in Fig. 3. The range is determined with relay switch S1 in position 0 and S4 as in Fig. 1. At this point, if the summation voltage is lower than the reference voltage relay switch S4 is energized. The input transformer is then set to provide a tenfold increase in voltage. This corresponds to the lower range and the condition for printing zero as a fourth digit does not arise. If the summation voltage is higher than the reference voltage these operations reverse and a zero as a fourth digit is printed. After these range-finding stages the impulse for doubler zero-setting is transmitted. The subsequent operations, the first relay decade, the printing of the first digit and so on can be followed from Fig. 3.

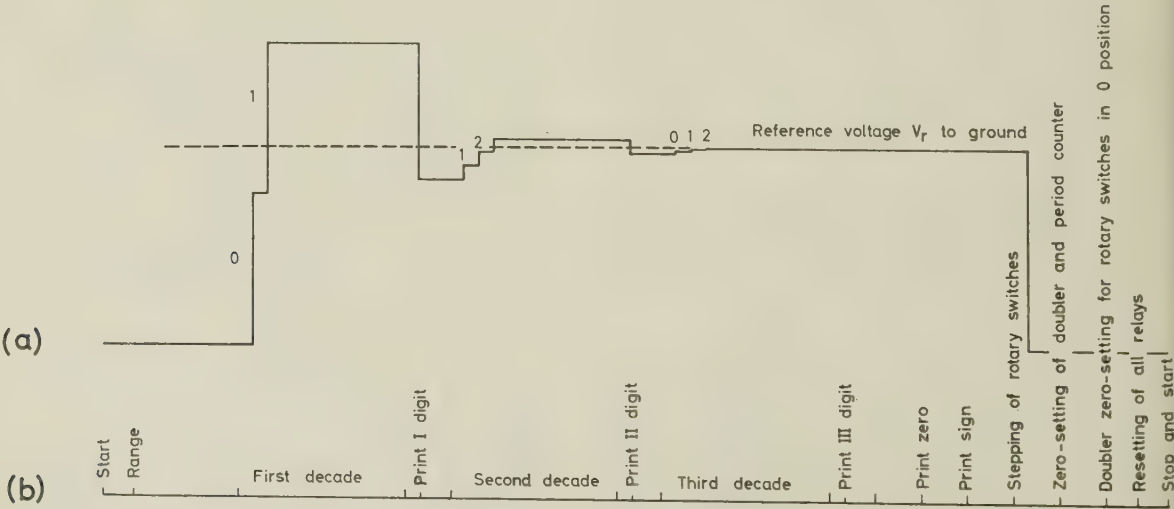


Fig. 3(a) Response of the reference voltage. (b) Sequence of main actions during one cycle.

Accuracy

accuracy of the machine is shown in Table 2 which is the result of the summation of a cosine test series at the 30 to 60 for every third degree. The coefficients of sine terms were as shown in Table 1.

30 × 60 points and wave numbers up to 35 is about 10 hours.

Acknowledgments

We should like to thank Professor G. Hägg for his kind interest and for the facilities put at our disposal. We also

Table 1

$h = 0 - 10$	0	-94	-26	10	5	-23	-21	110	-110	+14	-1
$h = 11 - 20$		27	0	-19	104	-110	43	0	73	-41	-18
$h = 21 - 30$		94	+110	71	28	59	-110	7	86	-110	-110
$h = 31 - 40$		11	-3	-110	65	48	-110	110	-61	-11	-79

deviations over the whole range are less than 4 units, an average of 1.2 units. In general, the computed values are below the theoretical values; this indicates some systematic error. For sums smaller than 100 the cause is nonlinearity of the doubler. For the present purpose preliminary crystallographic calculations this accuracy is considered quite satisfactory.

wish to thank Dr. J. Baecklund, Avesta Jernverk, for many suggestions and discussions at the beginning of this work.

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We also gratefully acknowledge the financial support of the Swedish Technical Science Research Council which made possible the construction of this machine.

Table 2

Point	Machine value	Theor. value	Diff.	Point	Machine value	Theor. value	Diff.
30	-179	-181.0	+2	45	+29	+31.3	+2.3
31	-32	-35.2	+3.2	46	-5	-8.3	+3.3
32	-141	-142.1	+1.1	47	-379	-380.0	+1.0
33	-140	-141.5	+1.5	48	-70	-71.6	+1.6
34	+639	+638.7	-0.3	49	+212	+212.3	+0.3
35	+912	+914.6	+2.6	50	-165	-166.3	+1.3
36	-55	-57.8	+2.8	51	+195	+195.9	+0.9
37	-404	-403.8	-0.2	52	+1010	+1011.0	+1.0
38	+434	+433.3	-0.7	53	+595	+595.6	+0.6
39	+521	+521.3	+0.3	54	-33	-33.8	+0.8
40	-324	-323.0	-1.0	55	+104	+103.8	-0.2
41	-382	-380.6	-1.4	56	-179	-179.1	+0.1
42	+225	+223.8	-1.2	57	-458	-456.1	-1.9
43	+148	+148.2	+0.2	58	+93	+93.6	+0.6
44	-182	-181.6	-0.4	59	+155	+157.1	+2.1

Performance

has been found possible to place 40 potentiometer units in an area of 0.27 m², in spite of screening problems and are therefore readily available for manipulation. Even the time needed to adjust the coefficient controls predominates over the balancing and printing time (3 s per point). To facilitate the rapid and correct adjustment of coefficients various arrangements have been made for the machine to store both the sine and cosine coefficients before commencing calculation.

Other operational advantages of this machine are a high rate of stepping with only sign indication and no printing, automatic stepping with stops after $\frac{1}{4}$, $\frac{1}{2}$ and 1 cycle, and multiplication of the result by a scale factor of two. The time for a two-dimensional Fourier summation with

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Radial shearing interferometer

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Abstract

A new type of wave front shearing interferometer is described in which two images of the wave front under test which are of different sizes are made to interfere. When the centres of the two images coincide, this results effectively in shear along the radial direction. It is shown that the interpretation of the resulting interferogram is comparatively easy. In addition, the instrument is extremely convenient to handle, since all the adjustments can be made with a white light source.

1. Introduction

IN shearing interferometers of the conventional type (Bates 1947, Drew 1951) two laterally displaced images of the wave front under test are made to interfere with each other. Such instruments have the advantage that the need for a reference surface is eliminated, so that they can be used, in principle, for testing optical surfaces of any size. In spite of this advantage, however, shearing interferometers have failed to find wide use in optical testing. One of the reasons for this is the fact that the interferogram does not cover the whole area of the wave front under test when the shear is large. Another is the serious difficulties which arise in the interpretation of the interferogram obtained with such instruments when the wavefront under test is afflicted with more than one aberration (Brown 1954).

Attempts have been made to overcome these drawbacks by subjecting the two images of the wave front under test to operations other than a lateral shear. Frequently, such a process results in the isolation of aberration terms of a particular class. Thus, for instance, comatic aberrations can be isolated by comparing the wave front under test with its mirror image (Gates 1955, Saunders 1955). However, the determination of the remaining aberration terms still presents difficulties.

The present paper describes a new type of interferometer based on an alternative approach to the problem (Brown 1959). In this, two images of the wave front under test, which are of different sizes, are made to interfere. When the centres of the two images coincide, this may be considered as equivalent to shear in the radial direction. Under these conditions the interferogram always covers the entire area of the wave front under test. As will be shown, it also results in an interferogram which can be very easily interpreted and which, in practice, often bears a close resemblance to the actual wave surface.

2. Optical system

The optical system of the instrument is shown schematically in Fig. 1. The basic interferometer consists of a plane-parallel plate M_0 with a semi-reflecting coating on one face, and two plane mirrors M_1 and M_2 . In such an interferometer, any ray incident on M_0 from the left is divided into

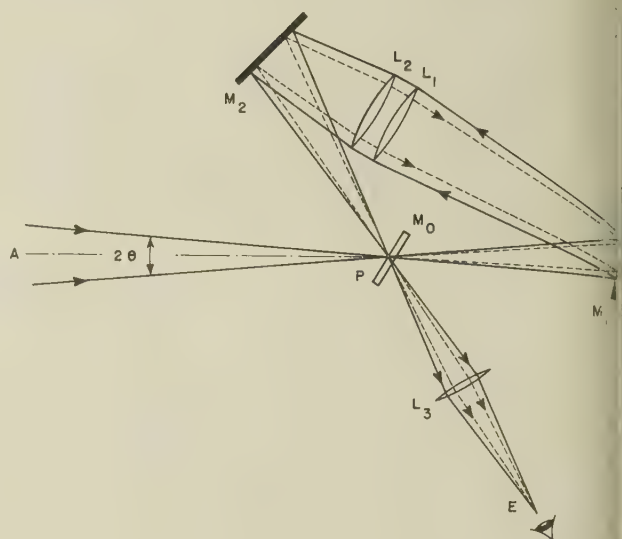


Fig. 1. Schematic diagram of the interferometer. M_0 , semi-reflecting plate; M_1 , M_2 , plane mirrors; L_1 , L_2 , objective lenses; L_3 , field lens.

two rays which traverse the path $M_0M_1M_2M_0$ in opposite directions before they are recombined at M_0 and emerge to the right.

To use this interferometer as a shearing interferometer, a converging beam from the system under test is brought to focus at a point P on the semi-reflecting surface of the beam-dividing plate M_0 and two lenses are introduced at L_1 and L_2 in the interferometer path. If L_1 and L_2 are adjusted so that the point P is at their principal foci, it is easily seen that the two beams diverging from P and traversing the closed path $M_0M_1M_2M_0$ in opposite directions are brought back to focus once again at P before emerging from the interferometer. If both the lenses have the same focal length, the two cones emerging from the interferometer will overlap exactly so that the whole field presents a uniform interference color. However, if their focal lengths differ, the two cones will be of different angles. Thus, if f_1 and f_2 are the focal lengths of L_1 and L_2 and 2θ is the angular aperture of the incident cone, the two emergent cones will have angular apertures equal to $(f_1/f_2)2\theta$ and $(f_2/f_1)2\theta$ respectively, as shown in Fig. 1. Accordingly, an eye placed at E will see two, superposed concentric images of the exit pupil of the system under test, the inner one of which will, in general, be crossed by interference bands as shown in Fig. 2.

The arrangement shown in Fig. 1 is satisfactory when the errors of the system under test are gradual and reasonably small. With systems which have abrupt surface errors of considerable magnitude, trouble may be experienced in getting good fringes because the two images of the exit pupil of the system formed by rays traversing the lens system

3. Theory

The form of the interference fringes observed when the incident wave front has various aberrations can be readily deduced by considering the simplified schematic diagram of the optical paths shown in Fig. 3.

We shall assume that any point R in the exit pupil of the optical system under test is defined in polar coordinates by its perpendicular distance from the line joining the Gaussian image point and the axial point of the pupil (expressed as a fraction r of the maximum semi-aperture) and the azimuth angle ϕ which this radius vector makes with the meridian plane. The departure of the wave front under test at R from the reference sphere having its centre at P and passing through the axial point of the pupil is then given (Hopkins 1950) by a series of the form

$$W(r, \phi) = C_{20}r^2 + C_{40}r^4 + \dots + C_{22}r^2 \cos^2 \phi + C_{42}r^4 \cos^2 \phi + \dots + C_{11}r \cos \phi + C_{31}r^3 \cos \phi + \dots \quad (4)$$

Since P and P' are conjugate points for the lens combination L_1, L_2 which is located in the interferometer path, the deviations of the wave front corresponding to the narrower of the two cones emerging from the interferometer, at a point R' specified by the coordinates (r', ϕ) , with respect to a reference sphere which has its centre at P' and touches the wave surface at its intersection with the axis, is given by the series

$$W(r', \phi) = C_{20}r'^2 + C_{40}r'^4 + \dots + C_{22}r'^2 \cos^2 \phi + C_{42}r'^4 \cos^2 \phi + \dots + C_{11}r' \cos \phi + C_{31}r'^3 \cos \phi + \dots \quad (5)$$

where r' , the perpendicular distance of R' from the axis A'P' is expressed as a fraction of the maximum semi-aperture of this cone.

In the same manner, the deviation of the wave front corresponding to the broader of the two cones emerging from the interferometer at a point R'' specified by the coordinates (r'', ϕ) , with respect to the same reference sphere, is given by the series

$$W(r'', \phi) = C_{20}r''^2 + C_{40}r''^4 + \dots + C_{22}r''^2 \cos^2 \phi + C_{42}r''^4 \cos^2 \phi + \dots + C_{11}r'' \cos \phi + C_{31}r''^3 \cos \phi + \dots \quad (6)$$

where r'' , the perpendicular distance of R'' from the axis A'P' is expressed as a fraction of the maximum semi-aperture of the wider cone.

The path difference between these two wave fronts at any point lying within the region of overlap of these two cones is therefore given by the relation

$$W'(r', \phi) = W(r', \phi) - W(r'', \phi) \quad (7)$$

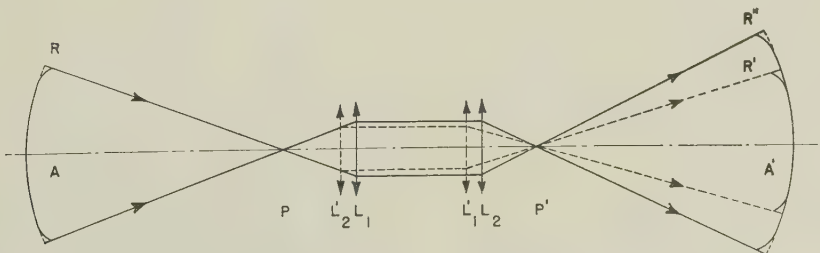


Fig. 3. Simplified schematic diagram of the ray paths in the interferometer.

2. Appearance of the field of view in the interferometer showing the two radially sheared cones.

L_2 in opposite directions are not located in the same plane. This difficulty can be eliminated by separating the lenses L_1, L_2 by a distance approximately equal to the sum of their focal lengths. If the exit pupil of the system under test is at a distance from the interferometer which is fairly large compared with the focal lengths of the lenses L_1, L_2 , both images of the exit pupil are then formed effectively at infinity. We assume that $\mathcal{R}$ is the reflection coefficient of the beam splitter M_0 , and $\mathcal{T}$ is its transmission coefficient, it is easily seen that the two beams emerging from the interferometer after traversing the closed circuit $M_0M_1M_2M_0$ in opposite directions, will have, at any point within the region of overlap, intensities I_1 and I_2 given by the relations

$$I_1 = I_0(f_1/f_2)^2 \mathcal{R}^2 \quad (1)$$

$$I_2 = I_0(f_2/f_1)^2 \mathcal{T}^2 \quad (2)$$

where I_0 is proportional to the intensity of the original incident beam. These must be approximately equal to obtain the maximum contrast of the interference fringes. This condition can be readily satisfied by choosing the reflectivity of the coating of the beam divider so that

$$(\mathcal{R}/\mathcal{T}) = (f_2/f_1)^2. \quad (3)$$

Assuming that $(f_2/f_1)^2 = 0.5$, this would require $\mathcal{R} = 0.33$, or $\mathcal{T} = 0.66$, which can be approximately secured with a thin sulphide film. Since the beam splitter is at an angle to the incident light, the reflectivity of the film is not the same as at normal incidence. In addition, the reflected and transmitted beams are differently polarized. In practice, however, the effects of these factors on the contrast of the fringes can be neglected.

where the value of r'' is chosen so that the point R'' coincides with R' . This corresponds to the condition

$$r'' = sr' \quad (8)$$

where s is the ratio of the semi-aperture of the inner cone to that of the outer cone. This fraction may be termed, for convenience, the shear ratio and is given, for small angles, by the relation

$$s = (f_2/f_1)^2.$$

From Eqns (7) and (8) it is seen that

$$\begin{aligned} W'(r', \phi) &= W(r', \phi) - W(sr', \phi) \\ &= C_{20}(1 - s^2)r'^2 + C_{40}(1 - s^4)r'^4 + \dots \\ &\quad + C_{22}(1 - s^2)r'^2 \cos^2 \phi \\ &\quad + C_{42}(1 - s^4)r'^4 \cos^2 \phi + \dots \\ &\quad + C_{11}(1 - s)r' \cos \phi \\ &\quad + C_{31}(1 - s^3)r'^3 \cos \phi + \dots \quad (10) \\ &= C'_{20}r'^2 + C'_{40}r'^4 + \dots \\ &\quad + C'_{22}r'^2 \cos^2 \phi + C'_{42}r'^4 \cos^2 \phi + \dots \\ &\quad + C'_{11}r' \cos \phi + C'_{31}r'^3 \cos \phi + \dots \quad (11) \end{aligned}$$

where

$$\begin{aligned} C'_{20} &= C_{20}(1 - s^2), \quad C'_{40} = C_{40}(1 - s^4), \dots \\ C'_{22} &= C_{22}(1 - s^2), \quad C'_{42} = C_{42}(1 - s^4), \dots \\ C'_{11} &= C_{11}(1 - s), \quad C'_{31} = C_{31}(1 - s^3), \dots \quad (12) \end{aligned}$$

Eqn (11) is of the same form as Eqn (5) and is, in fact, very nearly equivalent to it when s is small.

4. Reconstruction of the wave surface

It is evident from Eqn (11) that each of the individual aberrations of the wave front under test is reproduced in the interferogram unchanged except for a scale factor. Further, the scale factor for each term can be readily evaluated if the shear ratio is known. It follows, therefore, that in the case of a wave surface which suffers from only one aberration, the interferogram directly gives the form of the wave surface.

If, however, the wave front under test is afflicted with more than one aberration, these are usually reproduced on slightly different scales, so that the interferogram is no longer of exactly the same form as the wave surface. However, it bears a fairly close resemblance to it and the degree of approximation improves as the shear ratio s decreases. Considerations of coherence governing the visibility of the fringes set a lower limit to the value of s which can be used in practice, but it is readily seen that even if s is equal to 0.5, the coefficients involving r^2 do not differ from their actual values by more than 25%, while those involving r^3 and r^4 differ from their actual values by only 12.5% and 6.25% respectively.

The aberration function for the wave front is determined basically in the same manner as with the Twyman-Green interferometer; the calculation only involves one more simple step. In the first place, an analysis of the interferogram is made according to the usual procedure. This gives the values of the coefficients C'_{20} , C'_{40} , ..., etc., for the radially sheared interferogram. These have then only to be replaced by the actual aberration coefficients, which are obtained by dividing the values of C'_{20} , C'_{40} , ..., etc., by the appropriate scale factors taken from Eqn (12).

5. Residual aberrations

Since the beam dividing plate M_0 (which is traversed by the two sheared cones which have different angular apertures)

has to be of finite thickness, small systematic deviations are introduced in this manner can be evaluated from the formula given by Bates in the appendix to his paper (Bates 1949). For optical systems of moderate angular aperture, they can be made reasonably small merely by reducing the thickness of the beam divider and the angle of incidence of the rays on it (Hariharan and Sen 1960).

In the present case, with an $f/6$ cone and a shear ratio $s = 0.5$, the residual astigmatism due to a 1 mm thick beam dividing plate, assuming the principal ray to be incident at an angle of 30° , is about 0.17λ , while the primary coma is of the order of 0.02λ . This is within permissible limits for most work.

6. Adjustment

Since the optical paths traversed by the principal rays of the two sheared cones in this interferometer are always equal, the net path differences between the beams are always very small. Accordingly, it is possible to carry out all the adjustments with a white light source. However, for precise quantitative measurements involving photography of the fringes, a high-pressure, mercury vapour lamp with a green filter is preferable.

For convenience in adjustment, the entire interferometer (which can be made quite compact) is mounted on a cross slide on a short optical bench, the latter being set so that it is parallel to the optical axis of the system under test. To simplify construction, only one of the mirrors (say M_1) need be provided with fine adjustments for tilt as well as for movement through a short distance, the other two being fitted with rough, screwdriver adjustments. One of the lenses, L_1 should have a focusing adjustment, while M_2 should be provided with centering screws, so that its axis can be made to coincide effectively with that of L_1 .

The initial adjustment of the interferometer is carried out in two steps. In the first instance, the lenses L_1 , L_2 are removed, and the triangular interferometer is set so that the mirrors M_1 , M_2 are symmetrically placed with respect to the beam-divider M_0 , and there is no shear between the two emerging beams. This can be checked by observing the fringes formed with diffused light in the interferometer and verifying that the zero-order fringe covers the whole field.

After this, the lenses L_1 , L_2 are replaced and adjusted so that they are at distances approximately equal to their focal distances from a point coinciding with the surface of the beam divider. Under these conditions, the two images of a point P lying close to the former point formed by the rays traversing the interferometer in opposite directions will coincide with one another and with P itself. The wave front under test is then made to converge at or near the point P and the two images formed at P' are observed. By adjusting the fine focus setting of L_1 and the lateral position of L_2 , the two images are brought into the same plane and the two sheared cones are made truly concentric. Fringes will then be observed by an eye placed at E . The number of fringes crossing the field can be varied by traversing the interferometer at right angles to the axis PA by means of the cross slide, while the radius of the reference sphere with respect to which observations are being made can be changed by moving the interferometer along the axis PA .

Typical interferograms obtained with the interferometer are shown in Figs 4, 5 and 6. Fig. 4, taken on the axis of the lens, corresponds to practically pure defocusing, while Fig. 5 exhibits a mixture of astigmatism and defocusing. Fig. 6

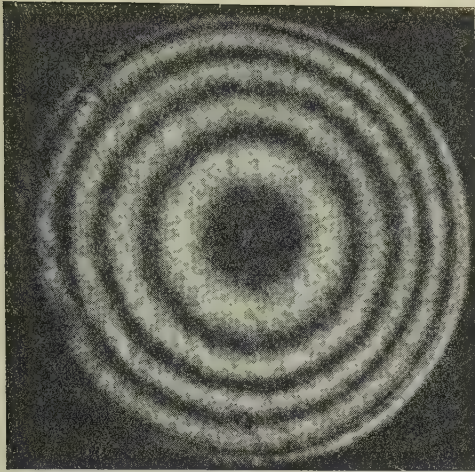


Fig. 4. Typical fringe system obtained with a slightly defocused lens, on axis.

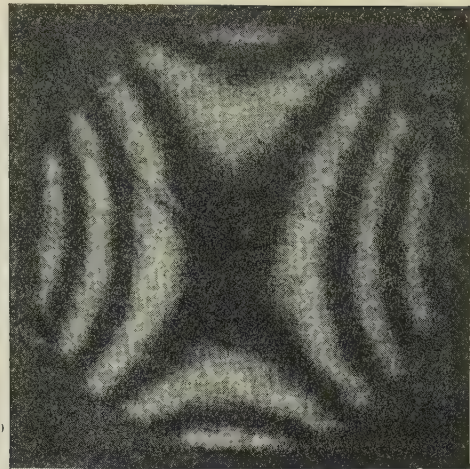


Fig. 5. Typical fringe system showing a mixture of astigmatism and defocusing.

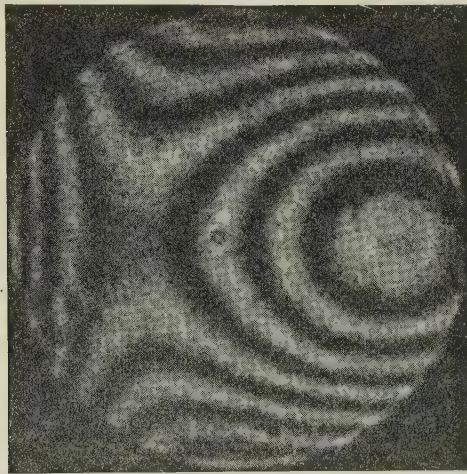


Fig. 6. Typical fringe system obtained with an uncorrected lens off-axis, showing a mixture of aberrations.

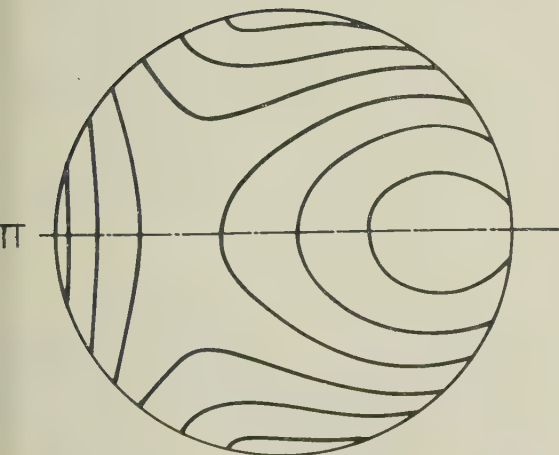


Fig. 7. Theoretical fringe pattern obtained by plotting the analytical expression derived from measurements on Fig. 6.

$$W' = -1.67 - 4.91r^2 + 0.61r^4 + 5.64r^2 \cos^2 \phi + 0.18r^4 \cos^2 \phi + 3.49r \cos \phi - 3.80r^3 \cos \phi.$$

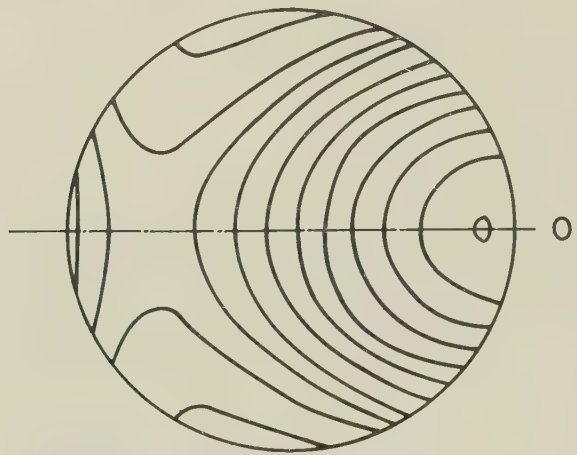


Fig. 8. Theoretical contour map of the wavefront corresponding to the fringe pattern shown in Fig. 7. (Shear ratio $s = 0.56$.)

$$W = -1.67 - 7.15r^2 + 0.68r^4 + 8.22r^2 \cos^2 \phi + 0.20r^4 \cos^2 \phi + 7.94r \cos \phi - 4.61r^3 \cos \phi.$$

was taken with an uncorrected lens, off-axis, and shows appreciable amounts of all the five Seidel aberrations.

To illustrate the technique followed in evaluating the aberration coefficients, the interferogram shown in Fig. 6 was analysed, according to the usual procedure, the analytical expression being taken to as many terms as necessary to secure a good fit. The theoretical fringe pattern given by this expression is shown in Fig. 7. The analytical expression for the actual wave front aberration was then obtained, as described in Section 4, by dividing each of the coefficients in the equation for the interferogram by the corresponding scale factor taken from Eqn (12). The theoretical contour map of the wave front obtained from this expression is shown in Fig. 8.

7. Conclusions

The present paper describes a new type of wave front shearing interferometer in which the two images of the wave front under test are sheared effectively in the radial direction. Under these conditions the fringe pattern always covers the whole area of the wave front under test. In addition, the interferogram bears a qualitative resemblance

to the actual wave surface, and its exact, quantitative interpretation is comparatively easy. Typical interferograms obtained with the instrument are presented and analysed.

Acknowledgment

The authors wish to thank the Director, National Physical Laboratory of India, for permission to publish this paper.

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Notes and comments

Chemical and Petroleum Engineering Exhibition

The Second Chemical and Petroleum Engineering Exhibition will take place at Olympia, London, from 20th–30th June 1962, under the joint sponsorship of the British Chemical Plant Manufacturers Association and the Council of British Manufacturers of Petroleum Equipment.

The Third Congress of the European Federation of Chemical Engineering will be held during the course of the exhibition with symposia on Process optimization, Interaction between fluids and particles, The handling of solids and The physics and chemistry of high pressures.

The Fourth Congress of the Federation of European Petroleum Equipment Manufacturers (Fédération Européenne des Constructeurs d'Équipement Pétrolier) will also be held during the exhibition from 25th–28th June at Church House, Westminster. Approximately 20 technical papers, covering Automation, New corrosion resistant materials, Temperature insulation, Aircraft refuelling and Future trends in the design of drilling equipment for the petroleum industry, will be presented.

Further information may be obtained from The British Chemical Plant Manufacturers Association, 14 Suffolk Street, London, S.W.1, or from The Council of British Manufacturers of Petroleum Equipment, 2 Princes Row, London, S.W.1.

New British Standards

The following British Standards have recently been issued:

British Standard 1991 : 1961, Recommendations for Letters, Symbols, Signs and Abbreviations: Part 2, Chemical Engineering, Nuclear Science and Applied Chemistry; Part 3, Fluid Mechanics; Part 4, Structures, Materials and Soil Mechanics; Part 5, Applied Thermodynamics; British Standard 1819 : 1961, Reference Tables for Thermocouples (Copper-Constantan); British Standard 3403 : 1961, Specification Indicating Tachometers for General Industrial Use; British Standard 3385 : 1961, Specification for Direct-reading Personal Dosimeters for X- and Gamma Radiation.

These may all be obtained from the British Standards Institution, British Standards House, 2 Park Street, London W.1.

Russian translating programme

The Department of Scientific and Industrial Research is translating into English and publishing every month seven of the leading Russian technical journals. These provide up-to-date information on Soviet progress in steel manufacture, castings, welding, rubber and plastics, production engineering, machines and tooling, instrument construction, textiles, wood processing, chemistry, biology and mathematics.

The Department also sponsors the translation and publication of Russian technical books and each year places on translations of hundreds of technical articles. These translations are obtainable from the new National Lending Library for Science and Technology, Boston Spa, Yorkshire.

Measurement of the figure of merit of a thermoelectric material

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Abstract

Description is given of a single piece of apparatus for measuring the three parameters involved in the figure of merit of a thermoelectric material. This apparatus uses direct current and is based on Harman's technique, in which a temperature gradient is established by means of the Peltier effect. It is demonstrated that the corrections for radiative heat transfer take a relatively simple form at low temperatures.

It is also shown that the figure of merit of a thermoelectric material can be obtained by measuring the maximum temperature gradient using the Peltier effect in a junction between the sample under test and a metal.

1. Introduction

The figure of merit z of a thermoelectric material is defined as

$$z = \frac{\alpha^2 \sigma}{\kappa} \quad (1)$$

where α is its absolute Seebeck coefficient, σ its electrical conductivity and κ its thermal conductivity (Ioffe 1957).

It is quite common to obtain the figure of merit by measuring the three parameters α , σ and κ separately, though it is a simple matter to combine the determinations of, say, α and σ . However, it was shown by Harman (1958) that, by employing the Peltier effect to establish a temperature gradient along a sample, all its thermoelectric parameters can be found in a single piece of apparatus.

This paper first describes the details of a method of applying Harman's technique, in which only direct current is passed, and then shows how the corrections for radiation have been determined in a particular case. An outline is then given of the determination of figure of merit by measuring the maximum temperature gradient which can be achieved, using the Peltier effect in a junction between the material under test and a metal.

2. Use of Harman's method

2.1. Experimental arrangement

In Harman's method the sample is suspended by leads soldered to its ends and a direct current is passed; the resulting temperature gradient is a function of the Seebeck coefficient and the thermal conductivity. The potential difference can be expressed in terms of the Seebeck coefficient and the electrical resistivity. One further measurement is necessary if all three unknown parameters are to be established. For example, the electrical resistivity may be found

independently if an alternating current is passed through the sample. Alternatively, the Seebeck coefficient can be determined in a separate experiment. The latter approach has been adopted in the work to be described here.

The experimental arrangement is shown in Fig. 1. The sample is soldered between two flat copper plates, which

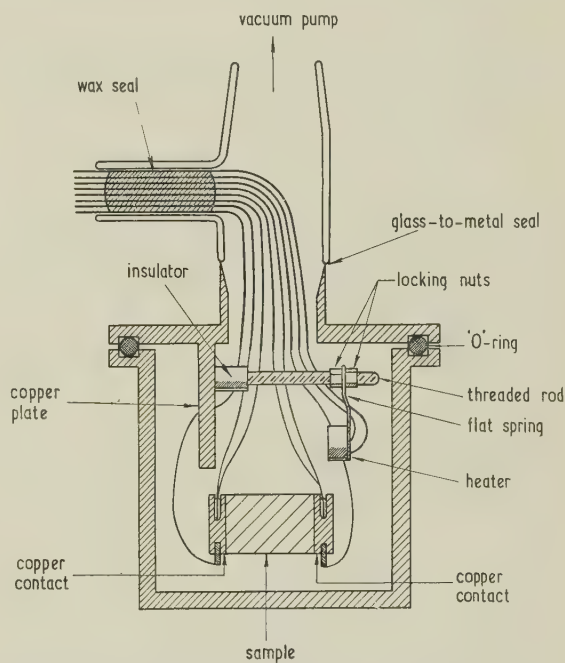


Fig. 1. Experimental arrangement for determination of thermoelectric parameters by Harman's method.

serve to ensure that the end surfaces are both isothermal and equipotential; 40 s.w.g. copper wires and chromel–alumel thermocouples are soldered to the end plates. If electrical contact resistances were suspected, potential probes would have been attached to the sample itself, but in the work on bismuth telluride alloys such contact resistances have been found to be negligible. The thermocouple wires are, therefore, used in measuring both temperature gradients and potential gradients in the sample.

A feature of the present apparatus is the provision for clamping the sample between a heater and a copper heat sink. The *clamped* position is used in finding the Seebeck coefficient directly. The *suspended* position, as in Fig. 1, is employed in the determination of the thermal conductivity and the

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electrical resistivity. Thus, although two separate experiments are needed, both are carried out in the same specimen chamber using the same contacts.

2.2. Measurement of thermoelectric properties

The potential difference V between, say, the two alumel leads in the *suspended* positions, with a current I flowing, is given by

$$V = IR + \alpha_a \Delta T \quad (2)$$

where α_a is the differential Seebeck coefficient between the sample and alumel (as determined in the *clamped* position), ΔT is the temperature difference between the ends of the sample and R is the total resistance. If contact resistances can be neglected, R is equal to $\rho l/A$, ρ being the resistivity of the sample and l and A its length and cross-sectional area.

Transfer of heat, other than by conduction through the sample, is minimized in the *suspended* position by evacuating the specimen chamber, but there is still radiation of heat from the surfaces of the sample and its contacts and, also, conduction along the lead wires. Harman, Cahn and Logan (1959) have formulated the general expression for use when the radiation losses are large enough to distort the isothermal surfaces appreciably. However, a much simpler expression may be employed when radiation is less important. By solving the heat-flow equation, assuming that the isothermals in the sample are planar, it may be shown that the equilibrium temperature difference ΔT is given by

$$\frac{\alpha_c IT}{\Delta T} = \kappa \frac{A}{l} + \frac{\beta Pl}{12} + \frac{\beta_c A_c}{2} + \frac{K_c}{2} \quad (3)$$

where α_c is the differential Seebeck coefficient between the sample and its copper leads and T is the absolute temperature. At this temperature β and β_c are the rates of heat radiation to the surroundings from the sample and its contacts respectively, per unit surface area, per unit temperature difference; P is the perimeter of the sample, A_c is the exposed area of the contacts and K_c is the effective thermal conductance of the leads to each contact.

In order to determine the correction terms, six samples of widely different dimensions were cut from a particularly uniform bismuth-antimony telluride alloy. (This alloy was prepared by a powder metallurgy process.) The experimental data are shown in the Table. The values of κ , β and β_c which fitted the experimental results most closely were obtained using the method of least squares. The small term involving K_c was calculated from the known conductivity of copper, chromel and alumel. The very small errors shown in the last column of the Table indicate how closely the simple Eqn (3) fits the results. It is concluded that this equation is perfectly satisfactory for interpreting measurements on thermoelectric materials at room temperature.

Data for samples of a bismuth telluride alloy

Sample	l (cm)	A (cm ²)	P (cm)	A_c (cm ²)	T (°K)	α (v deg ⁻¹)	ρ (Ω cm)	Experiment $\alpha_c IT / \Delta T$	Formula* $\alpha_c IT / \Delta T$	Error (%)
1	1.946	0.776	3.57	1.95	297	2.66×10^{-4}	3.41×10^{-3}	3.79×10^{-3}	3.76×10^{-3}	-0.8
2	1.385	0.776	3.57	1.95	297	2.64	3.38	5.02	5.02	0
3	0.938	0.776	3.57	1.95	296	2.64	3.37	7.12	7.16	+0.7
4	0.402	0.776	3.57	1.95	297	2.65	3.46	16.16	16.14	-0.5
5	1.015	0.152	1.90	2.57	296	2.68	3.40	1.63	1.63	0
6	1.887	0.316	2.67	2.41	297	2.65	3.31	1.85	1.86	+0.5

* Calculated for $\kappa = 8.20 \times 10^{-3}$ w cm⁻¹ deg⁻¹.

$\beta = 3.87 \times 10^{-4}$ w cm⁻¹ deg⁻¹ (corresponding to an emissivity of 0.66 for the sample)

$\beta_c = 2.32 \times 10^{-4}$ w cm⁻¹ deg⁻¹ (corresponding to an emissivity of 0.40 for the contacts)

$K_c = 0.08 \times 10^{-3}$ w deg⁻¹.

3. Determination of the figure of merit using semiconductor metal thermojunctions

3.1. Basic principles

The maximum lowering of temperature by means of the Peltier effect which can be achieved with a thermocouple (Ioffe 1957)

$$\Delta T_{\max} = \frac{1}{2} Z T_c^2$$

where T_c is the cold junction temperature and Z , the figure of merit of the couple, is given by

$$Z = \frac{(\alpha_1 - \alpha_2)^2}{(K_1 + K_2)(R_1 + R_2)}$$

α_1 , K_1 and R_1 are the Seebeck coefficient, thermal conductance and electrical resistance of one branch of the couple, α_2 , K_2 and R_2 are the parameters for the second branch. Unfortunately Z cannot be expressed simply as a function of the figures of merit z_1 and z_2 of the two branches as defined by Eqn (1). Thus a measurement of $\Delta T_{\max}$ does not generally yield z_1 , even if z_2 is known.

However, suppose that branch 1 were a semiconductor with a Seebeck coefficient of several hundred microvolts per centigrade degree and a ratio κ_1/σ_1 much higher than the value given by the Wiedemann-Franz law for metals. Clearly the second branch could then be a metal of dimensions that $K_1 \gg K_2$ and $R_1 \gg R_2$. In this special case

$$Z \simeq \frac{\alpha_1^2}{K_1 R_1} = \frac{\alpha_1^2 \sigma_1}{\kappa_1}$$

Although this approximation does not hold if branch 2 is composed of a good thermoelectric material for which α_2 is little higher than for a metal, it is worth considering when it is useful to measure $\Delta T_{\max}$ even in this case.

It is supposed that the dimensions of the metal branch 2 are adjusted so as to give the maximum value of Z ,

$$Z_{\max} = \frac{(\alpha_1 - \alpha_2)^2}{\{(\kappa_1/\sigma_1)^{1/2} + (\kappa_2/\sigma_2)^{1/2}\}^2}$$

From Eqn (5a) it may be shown that

$$z_1^{1/2} = Z_{\max}^{1/2} \left\{ 1 - \frac{\alpha_2}{\alpha_1} - \frac{Z_{\max}^{1/2}}{|\alpha_1|} \left(\frac{\kappa_2}{\sigma_2} \right)^{1/2} \right\}$$

In order to find z_1 it is necessary to know α_1 as well as α_2 and κ_2/σ_2 for the metal. However, it will be shown that there is a real virtue in the measurement of $\Delta T_{\max}$ and hence $Z_{\max}$, for a junction between a thermoelectric material and a metal. For a typical present-day thermojunction between two good thermoelectric alloys, Z may be as low as 3×10^{-3} deg⁻¹ and $\Delta T_{\max}$ about 90° C. This temperature

ence is so large that its measurement cannot be expected to give reliable information about the properties of the materials at any particular temperature. On the other hand, if one of the good thermoelectric alloys is joined to a metal, the maximum figure of merit of the couple falls to about $1 \times 10^{-3} \text{ deg}^{-1}$, with α then equal to less than 40°C . This temperature difference is large enough to be easily and accurately measured, but small enough to be related to the thermoelectric properties at the mean temperature.

3.2. Apparatus

The experimental arrangement, based on the principles described in the previous sub-section, is illustrated in Fig. 2.

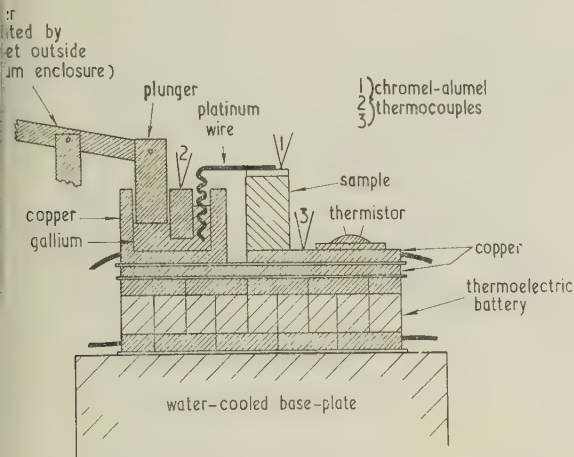


Fig. 2. Apparatus for direct measurement of the figure of merit.

The lower part of the apparatus is merely a thermoelectric battery, mounted on a water-cooled base-plate and used for control of temperature. The temperature of the hot junction of the couple under test is monitored by a thermistor, which forms part of a variable resistance bridge. The out-of-balance current from the bridge is amplified and used to control the current through the thermoelectric battery.

One end of the sample of thermoelectric material is soldered to a copper plate and a length of platinum wire is soldered to the other end. In the original experiments the free end of the wire was held in a clamp. However, each adjustment of length involved the opening of the enclosure and its subsequent re-evacuation. Thus, in the existing apparatus, as shown in Fig. 2, the platinum wire dips into a bath of oil, the level of which (when molten at 30°C) can be adjusted by a lever and plunger, controlled by a magnet outside the vacuum enclosure.

The temperatures at the cold junction and at the two sides of the hot junction are found using 46 s.w.g. chromel-alumel thermocouples.

3.3. Discussion

The apparatus has been used to check the figure of merit of a $\text{Bi}_2(\text{Se-Te})_3$ alloy with a Seebeck coefficient of $-211 \mu\text{V deg}^{-1}$ at 273°C . The sample was of 1 cm length and $0.4 \times 0.4 \text{ cm}^2$ cross-section and it was joined to a platinum wire of 0.085 cm diameter. Fig. 3 shows a plot of the maximum lowering of temperature against the apparent length of wire. The largest observed temperature difference was found to be 35.2°C at a cold junction temperature of 0°C , but it is necessary to make a correction for the heat transfer by radiation. The corrected value of ΔT_{max} is 37.3°C and the corresponding figure

of merit z for the $\text{Bi}_2(\text{Se-Te})_3$ alloy is $2.89 \times 10^{-3} \text{ deg}^{-1}$. This figure lies within about 3% of that calculated from independent measurements of α , σ and κ .

However, when the possible errors of the method are analysed, the results are less reassuring. The properties of the $\text{Bi}_2(\text{Se-Te})_3$ alloy are typical of contemporary materials for thermoelectric refrigeration. An error of 1% in the determination of α for such an alloy leads to an error of

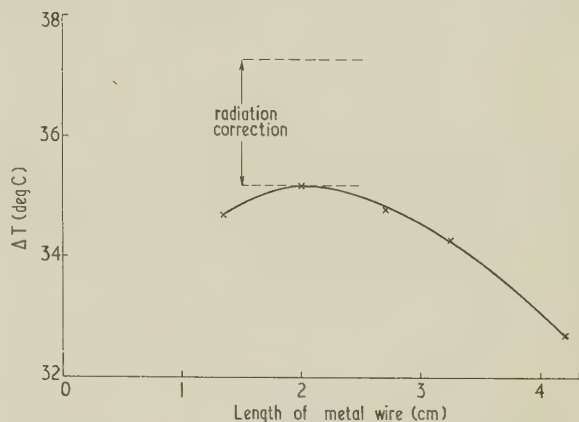


Fig. 3. Lowering of temperature with a semiconductor-metal thermojunction. Semiconductor: $\text{Bi}_2(\text{Se-Te})_3$, $\alpha = -211 \mu\text{V deg}^{-1}$, $1 \text{ cm} \times 0.4 \text{ cm} \times 0.4 \text{ cm}$. Metal: platinum, 0.085 cm diameter. $T_c = 273^\circ \text{K}$.

1.3% in the value of z obtained by the method described here. In practice, α can be measured to within 0.5% without difficulty. An error of 1% in the determination of ΔT_{max} is much more important, since it leads to an error in z of about 4.5%. The maximum temperature difference under the experimental conditions can, in fact, easily be established to within 0.1%, but the radiation correction that has to be applied may have an error of up to 25%. Thus the overall error in ΔT_{max} could be as high as 1.4% and the corresponding error in z would then be more than 6%. Future measurements should, therefore, clearly employ samples of considerably greater cross-sectional area so as to reduce the relative effect of radiation from the surroundings. It should then be possible to determine the figure of merit z with an error not exceeding 2 or 3%.

4. Conclusions

Experiments on the measurement of the thermal conductivity of a thermoelectric material using Harman's method have shown that heat transfer by radiation can be taken into account quite simply at room temperature. The interpretation of the results has involved the assumption of reasonable values for the emissivities of the sample under test and its contacts.

The figure of merit of a thermoelectric alloy has been obtained by measuring the lowering of temperature using the Peltier effect in a junction between the alloy and a metal. However, this work has shown the great importance of minimizing the transfer of heat by radiation if z is to be determined with the highest accuracy.

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Miniature cryostat for measurements on ferromagnetics between 1.6 and 300° K

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MS. received 2nd August 1961

Abstract

The cryostat requires external supplies of the liquids helium, hydrogen and nitrogen. It operates within a working width of 19 mm at the specimen position, and the vertical height from specimen to top is 20 cm. It is used with the Sucksmith ring balance. Very steady specimen temperatures are possible throughout the range 1.6 to 300° K, and it is economical to operate.

Introduction

THE cryostat described in this paper was designed because it became desirable to measure the magnetization of certain ferromagnetic materials in applied magnetic fields of up to about 20 kilo-oersteds, at temperatures down to about 2° K. The largest magnet available allowed a working space only 19 mm wide if this field were to be achieved. The general layout of this magnet, and also of most other small magnets, prohibits an arrangement like that of Hedgcock and Muir (1960) where there is a large volume of liquid helium kept below the level of the pole gap in any system that must be easily accessible for changing specimens.

The instrument chosen was the Sucksmith ring balance (Sucksmith 1939), mainly because of its simplicity and its versatility. However, it suffers from the disadvantage that with ferromagnetic specimens there is a tendency towards lateral instability when the vertical distance between the specimen and the lower stabilizing spiral (which must be at room temperature) is increased. To keep this distance fairly short is contrary to the usual requirement that for low losses from a bath of liquid helium, it should be inside a long container. The maximum length that was available between the specimen and a point vertically above it at room temperature was in this case 20 cm.

The main design requirements of the cryostat were that it should allow steady temperatures to be maintained for periods of not less than 10 minutes at any temperature from about 2° K upwards to room temperature; and that it should fit within the working width in the magnet of 19 mm and a vertical height of 20 cm. External supplies of liquid helium, hydrogen and nitrogen were available. The cryostat easily meets these requirements.

Description

A sectional diagram of the cryostat is shown in Fig. 1. The experimental specimen, in the form of a rough prolate ellipsoid 4 mm long, is suspended at the position F inside the pole gap of the magnet. The vertical force used in measuring the magnetization of the specimen is provided by the action of the magnetic field gradient produced by parallel currents of 50 A flowing in the heavy conductors shown fastened to the pole faces, after the method of Sucksmith and Thompson

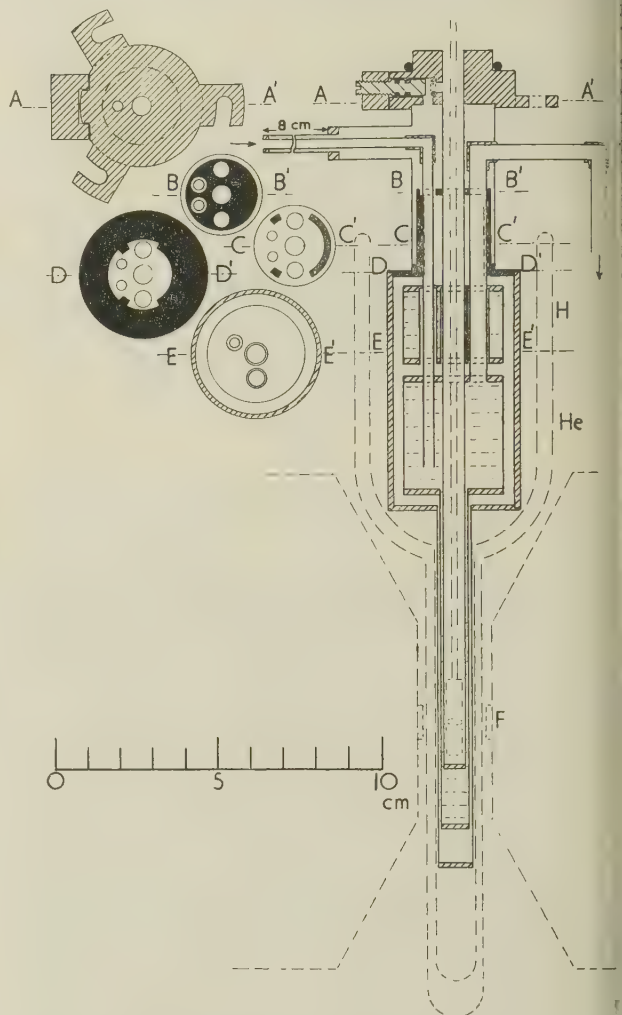


Fig. 1. Sectional diagram of the cryostat. The positions of delivery and exit tubes are schematic in the main diagram, and are indicated exactly in the cross sections. Solid copper parts are black and brass is shaded diagonally.

(1954). The innermost vertical tube surrounding the specimen is of German silver seamless tube of external diameter 6.0 mm and wall thickness 0.1 mm.* It connects at the top with the space containing the balance, which can either be highly evacuated or can be filled with an exchange gas of helium at low pressure.

* All tubes shown in Fig. 1 as single lines are of German silver. Wall thicknesses are 0.1 mm for diameters up to and including 6.0 mm, and 0.2 mm for bigger diameters.

the lower inner container and the 8 mm diameter tail tube welded to it hold liquid helium and their total capacity is 1.3 l. The upper inner container, of 12 cm³ capacity, is filled with liquid hydrogen; its function is to reduce heat transfer to the helium.

The 6 mm central tube and the two tubes for delivery of liquid helium and exit of gaseous helium are shielded from contact with the hydrogen container except where they pass through the top plate by having slightly larger German silver tubes soldered round them coaxially, as shown in the section EE' of Fig. 1. They are soldered to the top plate to ensure good thermal contact at that point. In this way the maximum length of path was obtained for the parts joining points at (or colder) and 20° K.

The space surrounding the hydrogen and helium chambers is evacuated and contained in an outer brass cylinder to which a 10 mm diameter German silver tail tube is attached coaxially with the 6 mm and the 8 mm tubes. This is in turn immersed in liquid nitrogen in a shaped glass Dewar vessel. The form of the delivery and exit tubes for helium is shown in Fig. 1. In this diagram they have been re-oriented so as to simplify the diagram. The hydrogen delivery and exit tubes are not shown, but are similar, and they end respectively at the bottom of the hydrogen chamber and at its top plate. The delivery tubes are made of 3 mm diameter German silver, and are vacuum protected throughout. They make thermal contact with anything between the points where the liquids first enter the cryostat and the top plate of the hydrogen chamber 15 cm inside. The actual disposition of the delivery and exit tubes is indicated in Fig. 2 and also in

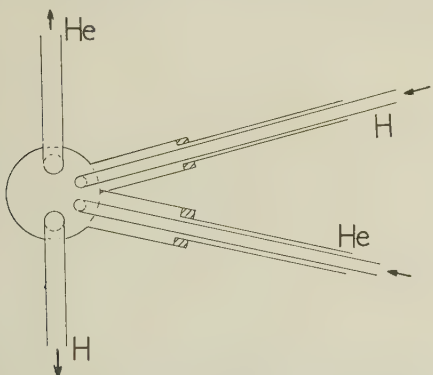


Fig. 2. Plan view of the delivery and exit tubes.

various cross sections in Fig. 1. It was determined largely by the problem of access with the external syphon tubes leading from the helium and hydrogen storage vessels. The thermal coupling of the syphon to the delivery tube is a common problem and is shown in detail in Fig. 3. The hydrogen delivery



Fig. 3. Detail of the connection from external syphon tube to the delivery tube. Vacuum protection exists throughout. The joint is made by a rubber tube, shown shaded.

enters 5 mm below the helium one, and is surrounded by a slightly narrower outer jacket.

Both the exit tubes and the central 6 mm tube are maintained at a temperature of about 77° K at the level of the

section BB' in Fig. 1. They are soldered to a specially shaped part made of copper, which extends inside the vacuum upwards from the top of the brass vacuum container at DD' to BB'. The delivery tubes do not touch this part, but are taken through clearance holes as shown in the section BB' of Fig. 1. The copper part is cut away as indicated in sections CC' and DD' so as not to touch any of the tubes anywhere below the level BB'. The whole of the copper part is made out of a single piece of solid copper for reasons of rigidity and good thermal conductivity, and also to avoid problems of soldering which would otherwise have arisen during final assembly. This copper part makes heat transfer by conduction to the hydrogen container much smaller than it would otherwise have been and also acts as a radiation shield. The vacuum case from DD' upwards is of German silver tube, 25 mm diameter and 0.2 mm wall thickness. There is very little transfer of heat along its length.

The whole cryostat is attached to, and may be detached from, the main balance assembly by means of a tri-leg arrangement, the lower part of which is made from brass and is shown in the section AA'. The cryostat vacuum space is pumped out via the central 6 mm tube through a valve in this part. After evacuation, and prior to admission of the exchange gas to the 6 mm tube, the valve is closed by screwing home a steel plunger by means of a screwdriver, against a neoprene O ring seated in the brass part. The vacuum space is thereafter left sealed off during operation of the cryostat.

The tri-leg allows sensitive adjustment of the position of the whole cryostat, so that the specimen mount can be prevented from touching the tube which surrounds it.

During assembly of the cryostat two different solders, with respective melting temperatures of 240° C and 390° C were employed, to facilitate the progressive soldering of joints in close proximity to each other.

Measurement of temperature

The mount which houses the experimental specimen at position F is a cylinder of pure copper 4.2 mm in diameter and 23 mm long, fastened to the end of a long tube of silica. Inside it are also placed a small manganin heating coil having a resistance at room temperature of about 10 ohms (below the specimen); and the elements of both platinum and carbon resistance thermometers (above the specimen). Independent current and potential leads to the thermometer elements are provided, although some leads are common to both thermometers. The leads are of fine copper wire, and are carried out along the silica tube. Standard potentiometric methods with a measuring current of 1 mA are employed for reading thermometer resistance down to 10° K. The carbon element is used below 20° K and the platinum above. Below 10° K where lead resistances become insignificant, a normal post-office box arrangement is used, with a thermometer current of 180 μA. Calibration of the platinum thermometer was by reference to the resistance data of Los and Morrison (1951) after having first determined its residual resistance. The carbon thermometer was calibrated against the vapour pressures of helium and hydrogen. It is sufficiently stable to make frequent recalibration unnecessary, although a significant magnetoresistive effect becomes apparent in strong magnetic fields below 4° K.

Operation and performance of the cryostat

For operating below 4.2° K the pressure in the helium chamber is reduced by pumping with a small rotary pump through the helium exit tube, after having first blocked the

inlet. Normally, a minimum temperature of about 1.6° K is attained in this way, although occasionally the temperature has been slightly lower. Any required temperature up to 4.2° K is obtained and maintained simply by altering the rate of pumping.

Specimen temperatures between 4.2 and 10.2° K are reached with the helium bath at 4.2° K, by balancing the power of the heating coil against the rate of transfer of heat across the exchange gas. The maximum power of the heater is 30 mw, although at these temperatures more than 10 mw is rarely necessary. In this range of temperature the reaction of the specimen temperature to changes in heater power is practically instantaneous, and temperatures steady to within $\pm 0.05^\circ$ K are easily achieved.

The range 10.2 to 20.4° K is obtained by putting liquid hydrogen into both inner chambers and pumping on the lower one. From 20.4 to 77° K is obtained with hydrogen in both chambers, using the heater, while above 77° K both chambers are empty, nitrogen is in the outer Dewar vessel, and the heater is used. In some of the temperature ranges a certain amount of manipulation of the pressure of the exchange gas is necessary. Stability as good as $\pm 0.1^\circ$ K can be attained between 10° and 40° K, and $\pm 0.2^\circ$ K above.

With one filling of the helium chamber, the specimen remains at 4.2° K for about 25 minutes. After completely filling and then reducing the pressures over the helium as far as possible, the temperature remains steady at 1.6° K for 10 minutes. The total heat leak to the helium bath is thus about 50×10^{-3} w, compared with the calculated conduction leak of about 10×10^{-3} w. This difference is presumably due to transfer by radiation, probably mainly room-temperature radiation down the tubes into the chamber. It proved

impossible for mechanical reasons to introduce bends in radiation shields into these tubes.

No liquid helium level indicators are fitted. Experience has shown that it is easy to tell when the helium chamber is full from the appearance of the frost on the tube carrying the exit gas away.

When operating with the helium bath at 4.2° K the best method seems to be first to put just enough liquid helium to cool the specimen down, and then to allow a slow automatic transfer of helium along the syphon tube by maintaining a slight over pressure in the external helium storage vessel. Under these conditions the bath remains indefinitely at 4.2° K. Operating for about 45 minutes at temperatures between 1.6° K and 10° K consumes one-half to two-thirds of a litre of liquid helium, including that used in cooling down initially.

Acknowledgments

The authors are grateful to Professor W. Sucksmith for interest and advice, to the Department of Scientific and Industrial Research for a grant to one of us (W. R. S.), and to Mr. D. Streets for his skill and care in the construction of the work.

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High-pressure hydrogen gas target

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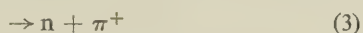
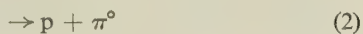
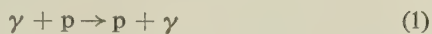
Received 19th June 1961

Abstract

Description is given of a hydrogen gas target, which has been designed to operate at a pressure of 450 lb/in² and at a temperature of -70° C, to be used in studies of x-ray scattering from hydrogen using a nuclear photograph emulsion technique. The choice of material for the entrance window and the high-pressure sealing of flanges is discussed.

1. Introduction

A CHAMBER, suitable for containing hydrogen at high pressure, has been constructed for use as a target in studies of reactions resulting from irradiation by high energy photons produced in the Glasgow 320 mev electron synchrotron. The reactions



are being investigated by means of a nuclear emulsion technique. In reactions (1) and (2), the recoil protons and, in reaction (3), the pions are recorded in photographic emulsions contained within the chamber.

Either a liquid hydrogen or a gas target could be employed for such investigations, but with the former, the emulsions must be placed outside the container walls. The (ν, p) cross section in the wall material, being large compared to that of reaction (1), would normally obscure the latter, and a high-pressure gas target was therefore chosen. In this case, the emulsions can be exposed within the gas, thereby permitting the observation of very low energy particles and largely eliminating background effects.

The silver bromide in photographic emulsions is reduced by hydrogen at room temperature. As this reaction can be inhibited by lowering the temperature, it was decided to maintain the target at -70° C, a temperature conveniently

attainable with an alcohol and Drikold (Imperial Chemical Industries Ltd.) mixture, and at an operating pressure of 450 lb/in². The target chamber was constructed from austenitic non-magnetic stainless steel, as it was necessary to apply a magnetic field across the entrance pipe to scrub the x-ray beam of electrons produced in the entrance window. The target design (as constructed by R. Y. Pickering and Co. Ltd.) is shown in Fig. 1. The conditions catalogued above, the dangers incurred in having the pressure vessel filled with hydrogen close to the synchrotron, and also the cycling of pressure and temperature raised difficulties on the sealing of flanges and the choice of window materials.

2. Window materials (theoretical)

The most suitable target window is one which produces the lowest flux of charged particles, predominantly electrons, when bombarded with x-rays. For an x-ray bremsstrahlung of 320 mev, the only important electron-producing reaction is pair production, which is described by

$$R_e \simeq kZ^2 n \frac{\rho t}{A}$$

while the photo-proton production (ν, p) is proportional to

$$R_p \simeq k'Zn \frac{\rho t}{A}$$

where R is the number of events per square centimetre of window, t thickness of window, n beam flux, Z atomic number, ρ density of material, A atomic weight, and K, K' are constants. It is obvious that ρ, Z, t must be kept as low as possible. In order to find the thicknesses of various materials that would withstand a pressure of 450 lb/in², the following simple theory was developed.

With the two assumptions that:

- (a) the window assumes the shape of a section of a sphere; and
- (b) edge effects due to clamping are neglected;

it is found that

$$\tau = \frac{Pa(1 - \cos \alpha)}{T \sin^3 \alpha}$$

where τ is the unstretched thickness of material, P excess pressure, a radius of window aperture, α half angle subtended by the aperture at centre of curvature of window, and T tensile strength of material.

Thus, the thickness of various materials necessary to withstand a pressure of 450 lb/in² over a 1½ in. diameter window can be calculated. These results are shown in the second column of the Table, together with data for the

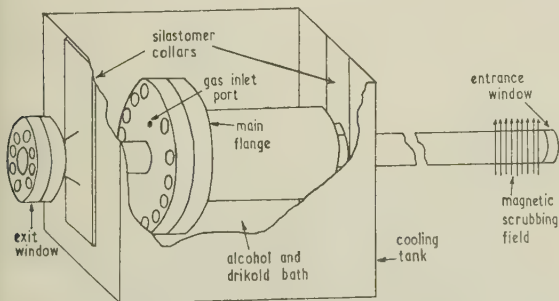


Fig. 1. Cooling tank and pressure vessel.

Charged particle production at target windows

Window material	τ (thou)	$\tau \rho Z^2/A$	$\tau \rho Z^2/A$ relative to Mylar	$\tau \rho Z/A, (\gamma, \rho)$ relative to Mylar
Aluminium	~ 30	507	10	3.45
Brass	8	865	17	2.64
Copper	11	1250	24.6	3.81
Duralumin	5	83	1.64	0.57
Mylar	15	50.7	1.0	1.0
Steel	4	368	7.25	1.25

relative number of charged particles produced in the critical window thickness required to withstand 450 lb/in². It is obvious that Mylar is the most suitable material for this experiment.

3. Window materials (experimental)

A series of experiments were carried out on the bursting of sheet Mylar* clamped in a replica of the target entrance window. For sheets of varying thickness, the results are shown in Fig. 2 and compared with the theoretical values.

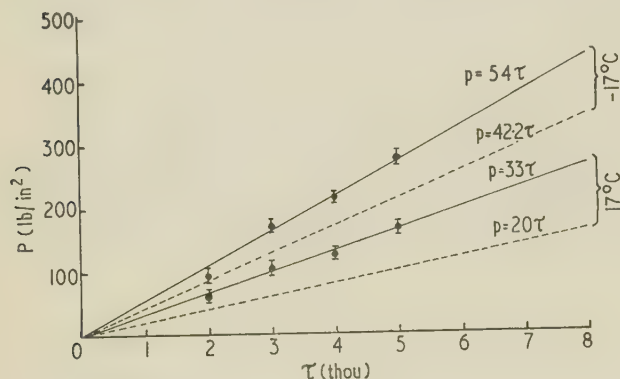


Fig. 2. Bursting pressure for Mylar windows.

— experimental graphs. --- theoretical graphs.

This experiment was carried out on a 2 in. diameter window at two temperatures, 18°C and -70°C. In both cases, it was found that the Mylar withstood a greater pressure than predicted by theory. Measurements showed that assumption (a) is essentially justified, and thus edge effects probably contribute largely to this apparent 'increase of strength'. However, as this might be expected to occur for all materials, the relative values given in the Table probably hold.

Thus to obtain a safety factor of between 2 and 3, a window thickness of about 0.03 in. of Mylar is required. The thickest sheet Mylar (made by du Pont de Nemours and Co., U.S.A.) available at the time of writing is 0.01 in. An experiment was thus carried out to investigate the bursting conditions of several sheets of Mylar together. The results are shown in Fig. 3, where the bursting pressure is plotted against the number of layers of 0.005 in. thick Mylar. It was found that the pressure withstood varies linearly with the number of sheets, so that multilayer windows are as effective as single ones. Hence, three 0.01 in. thick sheets of Mylar were used on the entrance window of the hydrogen gas target.

* For thicknesses up to 0.005 in., Melinex, the equivalent Terylene sheet produced by Imperial Chemical Industries Ltd., was used.

4. Sealing of flanges

Several methods of sealing the main flange were attempted. The first and most interesting was with Silastomer O-ring

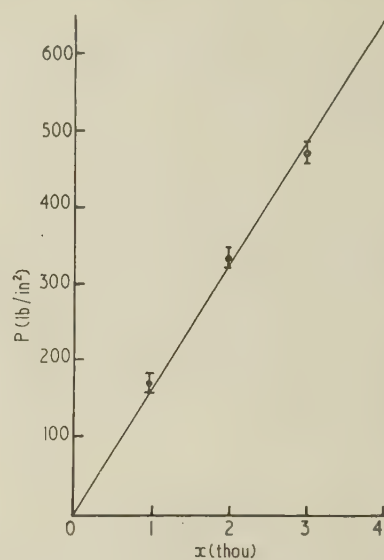


Fig. 3. Layered Mylar windows.

$$P = 162x = 32.5\tau \text{ (where } \tau = 5x\text{)}.$$

(by George Angus and Co. Ltd.). The author found that while these seals held perfectly at room temperature, leaks developed as the target was cooled. The reason for this is obvious from Fig. 4. This is a graph of the variation of

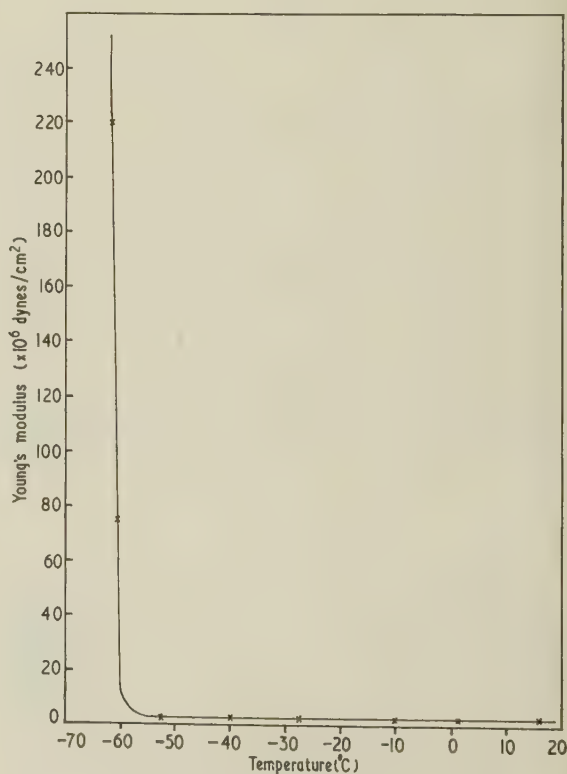


Fig. 4. Temperature dependence of Young's modulus for silicon rubber at a 2% extension.

ing's modulus of silicone rubber with temperature for a n extension. The marked change in gradient at about 5° C indicates the onset of the brittle glassy state of the ber, with consequent loss of its usual elastic properties. temperatures down to this transition point, despite its ter expansion coefficient than steel, the rubber, com- ised in an O-ring groove, can distend to take up the gap to differential contraction and thus make good the seal. ow the transition point, the rubber and steel still contract erentially, but the rubber in its glassy state contracts in its rmed shape away from the walls of the groove, and so a c develops. The rubber is still to some extent flexible n compressed and thus, if the seal can be tightened at point, the leak is stopped. For the flange on the exit ow, tightening was possible and a Silastomer O-ring was d. Owing to the design of the cooling tank, the main ge was inaccessible when cold and other methods of ling were therefore attempted.

ndium and lead wire, $\frac{1}{16}$ in. diameter, was placed round face of the flange and compressed to form a flat gasket. is technique was found unsatisfactory as the seals failed der high pressure, even at room temperature.

Corrugated steel gaskets, coated with Silastomer rubber, re used and were fairly successful, though unreliable. The all leaks occurring with this method were considered to ke it unsuitable for prolonged operation.

The final and successful method was sealing with hollow el O-rings (by Wills Pressure Filled Joint Ring Ltd.) filled h an inert gas to a pressure of 600 lb/in² at room tempera- e, and coated with fluon. With the flanges clamped up y tightly these rings proved most satisfactory as their ilience, although considerably less than silicone rubber, is untained at all temperatures.

The plastic-covered steel ring technique used by this hor is very similar to that of Weitzel *et al.* (1960). Their ethod is to have a semi-circular ring embossed on a flange

and to squeeze a thin sheet of plastic between this ring and the plane face of the other flange.

5. General

A method was required to join the cooling tank to the pressure vessel over the entrance and exit pipes in order to prevent alcohol leaks. At the same time, it was considered expedient that these coupling sections should be to some extent pliable, to allow for small adjustments while aligning the target in the beam. A wood mould was constructed to cast silicone rubber collars from cold cure Silastomer (by Midland Silicones Ltd.) to fit over the pipes of the target. The method was found to be both simple and effective, aligning adjustments being made at room temperature when the rubber is still flexible, before cooling takes place.

The target assembly has been successfully used with the Glasgow Electron Synchrotron in a photographic emulsion exposure to study the reactions (2) and (3). It is hoped to complete an exposure later this year to study the Compton scattering reaction (1). In the future, a programme is envisaged on the study of photo-induced reactions in gases, commencing with deuterium and extending to more complex elements.

Acknowledgments

I should like to thank Mr. A. L. Cockroft and Dr. P. V. March for their continued help and guidance, Mr. J. McElroy for his assistance in the later stages of this work and Professor P. I. Dee, for his interest and encouragement throughout the project.

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Height of waves in hydraulic models by the method of stereoscopy

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MS. received 2nd June 1961

Abstract

The analogy between the flow of shallow water over a horizontal plane and the two-dimensional unsteady flow of a compressible gas is well known, and an interpretation of the behaviour of the hydraulic model, and hence of the gas, requires, at any instant of time, the distribution of water depth over a horizontal plane. Because the flow may often be of a time-dependent type, a photographic method has obvious advantages, and the only one which appears suitable is the method of stereoscopy. In this application three lenses are used, and the glass table over which the water flows is lit from below by well-diffused light from electronic flash. The water surface is marked by the use of floating markers obtained by the introduction of teleprinter 'confetti', a by-product of the punching of paper tape. The optimization of the optical system and the method of obtaining the height of any of the floating markers, and, hence, of the water surface, is described: with a moderate outlay water depths can be measured to 0.005 in.

Introduction

THE authors are currently investigating the problem of supersonic flow in systems of radial diffusers by the hydraulic analogue, and are interested in the time-dependent character of the flow which obtains during the starting process. The method of stereoscopy, since it covers the entire field in an instant and thus records the water surface shape for subsequent analysis, was to be preferred to the devices which record changes in depth at single points; in addition, the method, apart from the use of floating markers, involves the introduction of no disturbing elements into the flow.

The first part of the discussion covers the optimization of the optical system, and a diagram is introduced which assists towards a rapid choice of the optics for other circumstances. The second part describes some experimental details and gives an idea of the accuracy achieved.

Theory and selection of the optical system

The stereoscopic arrangement is shown in Fig. 1. The absolute parallax in the image plane II, of a point B located in the datum object plane 00, is the length P_B which is easily seen to be given by

$$P_B = b + \frac{vb}{H} \tag{1}$$

The parallax of a point A, distant h_a above the datum plane, is given by

$$P_A = b + \frac{vb}{H - h_a} \tag{2}$$

whence the difference in parallax p is given by

$$p = \frac{vbh_a}{H(H - h_a)}$$

Thus if p is measured from two negatives exposed in the image plane, then h_a may be calculated. On the other hand

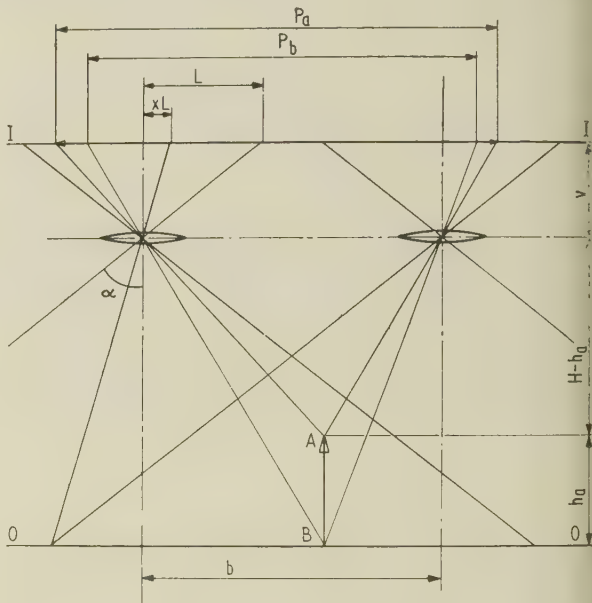


Fig. 1. Geometry of optical system.

if reprojection takes place (which method was in fact used) so that the image is cast in a plane co-incident with the datum object plane, 00, the difference in parallax is now

$$p = \frac{bh_a}{H - h_a} \tag{3a}$$

The problem of the optical system depends upon the choice of the following variables: (i) extent of the object field seen stereoscopically, the stereo field; (ii) the angle of view of the lens and its focal length; (iii) the correct choice of the separation b and the height H ; (iv) the degree of overlap of the fields of each lens; this is determined by the parameter x shown in Fig. 1.

The stereo field viewed by a pair of lenses is a distance $H \tan \alpha(1 + x)$ along the centre-line joining lens axes and a distance $2H \tan \alpha$ normal to this axis. The angle of view α is the semi-angle of view along one side of a square format, or

$$\tan \alpha = \frac{1}{\sqrt{2}} \tan \frac{\alpha^1}{2}$$

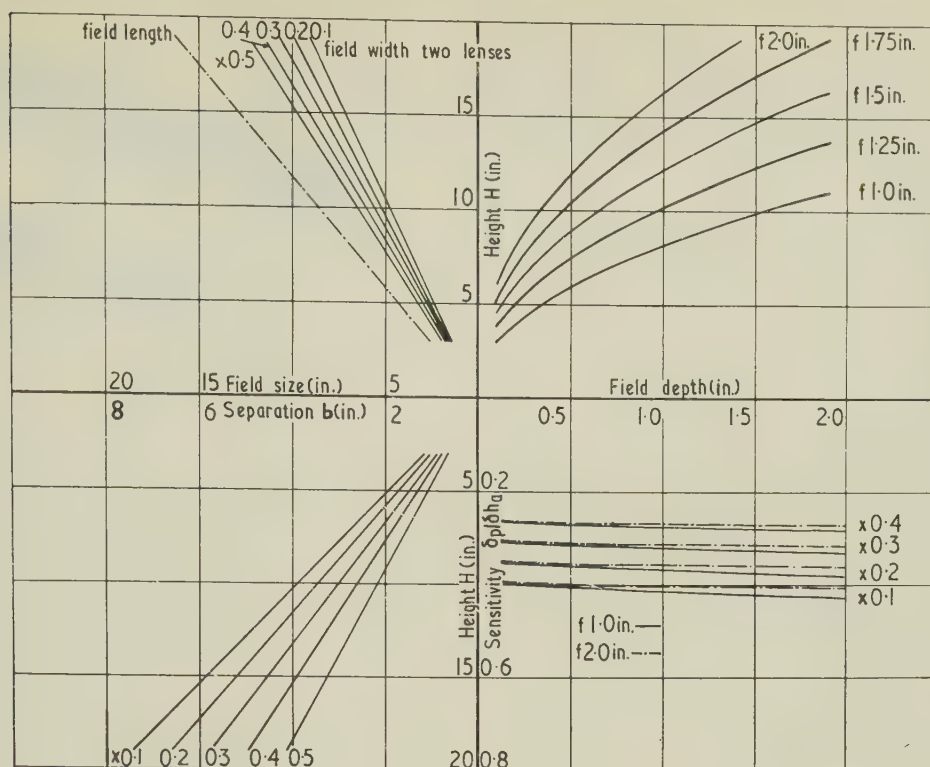


Fig. 2. Selection curves for geometry of stereoscopic optical system.

α^1 is by conventional definition the angle subtended by diagonal at the rear nodal point. The choice of α is not arbitrary, as the higher this angle is the better the sensitivity ratio $\delta p / \delta h_a$. By differentiating Eqn (3a), then

$$\begin{aligned}
 \frac{\partial p}{\partial h_a} &= \frac{b}{H} \left(1 - \frac{h_a}{H} \right)^{-2} \\
 &\approx \frac{b}{H} = (1 - x) \tan \alpha
 \end{aligned}
 \quad (4)$$

neglecting the term $(h_a/H)^2$ compared with unity. If it is required that contiguous areas be joined, thus prescribing the value of x , then a high sensitivity depends entirely on a wide viewing angle. In view of the aberrations associated with wide angles of view, a normal wide angle lens, with a wide angle of view, was chosen.

The choice of the remaining lengths bH and focal length F depends on more involved considerations, chief of which is the amount of focus desired in the object space. It may be shown (C 1937), when the ratio H/F is not large, that the depth of focus in the image space is given by $h = 2neH(H - F)/F^2$. In terms of magnification $H/F - 1 = m$, that

$$h = 2nem(m + 1)
 \quad (5)$$

where n is the numerical aperture, e the diameter of an acceptable circle of confusion.

An acceptable value of e depends on the resolving power of the lens and emulsion. It did not seem likely that the overall definition would be worse than 50 lines per mm. Accordingly, a circle of confusion of 0.001 in. was assumed. The working aperture was selected at $f/11$ to be consistent with best lens performance and adequate light intensity. In Eqn (5), a given desired depth of focus, i.e. maximum

prevailing distance from crest to trough of the waves, fixes the magnification m which in turn fixes the stereo-field, if the focal length is known. To facilitate a choice among the variables, the set of curves relating all of these variables has been drawn up in Fig. 2.

In the present case a further consideration was involved owing to the presence of objects projecting above the water surface which tended to mask portions of the water surface, a circumstance rendered worse when the separation b of the lenses was increased. A low value of b for a given b/H was then desirable so that the camera could 'see' into the shadows. Since b is roughly proportional to field covered, this requirement indicates a short focal length in this instance. From the readily available series of wide-angle photographic objectives the choice of focal length is greatly reduced. The lenses chosen were, in fact, $f/3.5$ Dalmac lenses by Dallmeyer, optimized for use at $f/11$ and of focal length 1.38 in. The stereo width (along the axis joining the lens centre-lines) was 5.4 in., with two lenses and 9 in. with three. The depth of focus in the object plane was 0.8 in., the separation b equal to 3.6 in. and the height H above the datum plane equal to about 9 in.

The curves of Fig. 2 enable a selection of the optical arrangement for a wide variety of possibilities including a variation of overlap ratio x once the requirements as to field coverage and height of objects have been selected. It should be noted that when m is less than the value of $2/(1 - x)$ then the images on the negatives will begin to interfere, necessitating either a mirror arrangement or the taking of pictures serially.

Experimental technique

The problem of marking the water surface was solved by the use of the fine paper 'confetti' produced by a teleprinter

punch. These small disks of paper, little more than a millimetre across, float on the surface, and by locating the electronic flash heads under a diffusing screen located under the glass surface over which the water flows, no trouble with specular reflection is encountered and the disks are seen dark against a light background on the final prints. As stated previously the method of reprojection was used. Thus the negatives (glass plates in this instance in order to avoid processing distortion) are replaced in the camera, illuminated from behind one at a time and enlarged prints produced in the plane of sharpest focus, i.e. approximately in the centre of the depth of field of interest. Since the camera had to be raised slightly, it was mounted on a machine tool slide and raised by a known amount, without disturbing the focus of the lenses (which had, in fact, been focused accurately with the aid of a scratched glass plate and magnifier). The flat surface carrying the print material was also raised above the datum plane by the same distance and maintained parallel to this plane. The value of this reprojection method lies in the ease of measurement on the large prints and the cancellation of distortion due either to lens distortion or camera levelling. To obtain prints free of dimensional changes, Kodak Bromide Foil card was used for the prints and gave a good permanent record. The measurement of parallax was carried out with a stereometer bar without the aid of a stereoscope, as it was found easy to locate corresponding images of particular paper markers. Calibration and orientation of the pictures was found possible by the introduction of three points of known height into the field. The height of any object h_a above the datum plane could then be obtained from the formula

$$h_a = h_1 \left(1 + \frac{b}{P_1} \right) / \left(1 + \frac{b}{P_a} \right) \quad (6)$$

where h_1 is the height of a known point. A contour plot of the water depth in the model which shows the 'supersonic' flow into a set of radial-compressor diffuser vanes is given in Fig. 3.

A check on the accuracy of the system was carried out

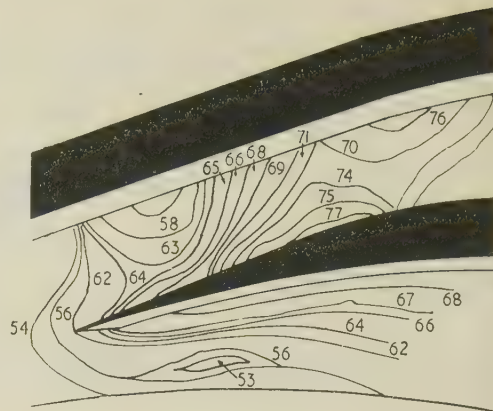


Fig. 3. Typical contour plot at inlet to cascade.

using slip gauges of $\frac{1}{4}$ in. up to 1 in. thickness in various parts of the field. An error of no greater than about 0.005 in. height was found. Provided precautions are taken regarding development and drying of the photographic material in accordance with the manufacturers' instructions this accuracy could be improved if the actual measurements of parallax could be improved. This, however, would require a rather expensive set-up unless access to one of the elaborate plotting machines used in map drawings is obtained.

Acknowledgments

The authors are indebted to the Department of Scientific and Industrial Research for the support afforded to the project and to Professor S. A. Tobias for his encouragement and support.

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Recording refractometer for measuring refractive indices of optical glasses over a wide range of wavelengths

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Abstract

Description is given of a spectrometer on which refractive indices of prismatic specimens have been measured from near ultra-violet to the near infra-red. The relations between accuracy of measurement and tolerance on the measurement and wavelength are considered. Values of refractive index for six optical glasses are quoted for the wavelength range 366 m μ to 2300 m μ and with an estimated accuracy of ± 0.00003 or better.

1. Introduction

THE development of moiré fringe measuring techniques using diffraction gratings for linear measurements is now well established (Guild 1960) whilst the advantages of using moiré fringes for continuous angle measurements in connection with the measurement of refractive index has been reported by one of us (Habell and Brittan 1960). In the present system, a radial grating is used to measure the rotation of a prism in a spectrometer so that a continuous record correlating angular rotation with dispersion of the spectrum for various spectral lines is obtained. From the resulting record the refractive indices of the prism are calculated.

2. The spectrometer

Figure 1 shows the optical arrangement. Light from any of the discharge lamps is selected by means of the rotatable plane mirror M_1 and after reflection by the mirrors M_2 , M_3 , M_4 is focused on to the upper half of the slit S . The spectrometer is in general of conventional auto-collimating type employing a deflecting mirror M_5 and a 20 in. focal

length collimating mirror M_6 , the specimen to be measured being usually made into a 30° back surface aluminized Littrow prism. The light which is returned by the prism along its original path in the horizontal plane is deviated slightly in a vertical direction so that it emerges through the lower half of the slit. This beam is then deflected by the mirror M_7 and is focused by the mirror M_8 on to the detector. Although the minimum deviation condition is preserved an error in the measurement of the required angle is introduced due to the curvature of the slit image. A correction for this error is applied using the method of Forrest, Straat and Dakin (1956). The light beam emerging from the spectrometer is interrupted at 800 c/s by a rotating chopper placed close to the slit; the signal which is obtained from an appropriate detector (normally a Kodak Ektron lead sulphide cell) and fed into the Mervyn homodyne amplifier is thus modulated at this frequency. The amplifier which is tuned to 800 c/s therefore amplifies only the required signal, any effects due to stray light falling on the detector being minimized. This amplified signal is fed to one pen of a recorder.

3. Angle measurement

In the previous system described (Habell and Brittan 1960) a coarse radial grating was mounted before the worm drive to the rotating table. In the present system a considerable improvement in accuracy is effected by mounting a finer grating consisting of 10 800 radial lines directly on the rotating prism table (Fig. 1), thus eliminating errors which previously were introduced by the worm wheel drive. Moiré fringes are formed between the main grating and the two fixed index gratings having the same grating spacing, the

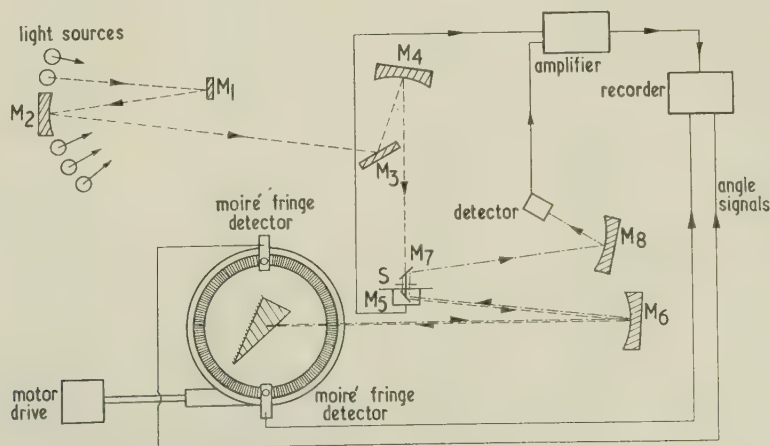


Fig. 1. Schematic diagram of recording refractometer.

two reading heads being positioned at opposite ends of a diameter of the table. By rotating each index grating so that its rulings are slightly inclined to those of the main grating, the separation of the moiré fringes is adjusted until approximately one fringe fills the aperture of the optical system shown in Fig. 2. The collimated beam of light which

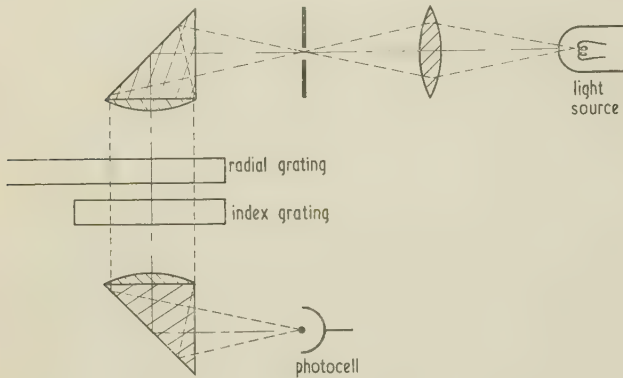


Fig. 2. Moiré fringe detector.

traverses the two gratings is $\frac{1}{2}$ in. in diameter so that the intensity of the light falling on the detector is the result of averaging the position of more than 150 lines on the grating. The electrical output of each detector (Mullard OCP 71 phototransistor) is amplified by a two-stage d.c. amplifier, the two outputs being fed to two pens of the recorder. When the grating is rotated the period of the sine wave produced by the moiré fringe detectors is 2 minutes of arc, this being the angle through which the main grating must be rotated to cause one fringe to traverse the field.

4. Experimental procedure

A simplified version of a section of record obtained, showing the form of the spectral lines and one set of moiré fringes, is shown in Fig. 3 (the other set of moiré fringes is omitted for reasons of clarity). To obtain the record, the prism table is rotated at a uniform speed so that all the desired spectral lines are obtained, the rotation being from short to long wavelengths as illustrated in the upper half of Fig. 3. Rotation of the table is then continued at a faster rate until just

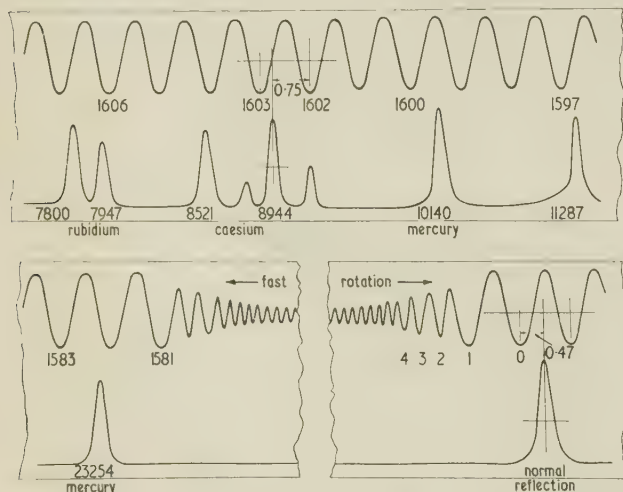


Fig. 3. Recorder trace.

before the reflection (called hereafter the normal reflection) is obtained from the hypotenuse of the prism, where the rotation is slowed and the normal reflection is recorded the same way as the spectral lines; this is shown in the lower traces of the figure. The angle of incidence for each spectral line is calculated from the number of whole fringes and fractions of a fringe between each line and the normal reflection on the recorder chart. Thus the value for the 8944 Å line is $1602.75 + 0.47$, i.e. 1603.22 fringes, giving an angle of incidence of $53^\circ 26' 26''$. To eliminate the effect of the main grating not having its centre exactly on the axis of rotation the angles of rotation are calculated using the mean value of the two sets of moiré fringes. The time taken to obtain a complete record of spectral lines between 0.36 and 2.3μ and the normal reflection depends to some extent on the dispersion of the prism, the average time for optical glasses being about 45 minutes; 25 minutes of this is taken for recording the spectral lines and 20 minutes to record the angle between these lines and the normal reflection.

5. Accuracy of measurements

Provided that the usual precautions are observed corrections are applied regarding temperature, atmospheric pressure and humidity (Glazebrook 1923) and if the prism to be measured is of sufficient homogeneity with faces which are flat and free from pyramidal error, the accuracy of measurement of the refractive indices is mainly determined by the accuracy with which the angle of the prism and the angles of incidence in the positions of minimum deviation are determined.

For a Littrow prism at minimum deviation the refractive index is determined from the equation $N = \sin i / \sin r$, where i = angle of incidence and r = angle of refraction = angle of prism at minimum deviation. For 30° prisms the permissible tolerance on the measurement of the angle of incidence for an accuracy of 0.00001 in the refractive index is shown in Fig. 4 (curve A). This shows that for normal optical glasses the angle tolerance is of the order of 1.3 seconds. A similar curve of the tolerance on the accuracy of measurement of the prism angle is also shown in Fig. 4.

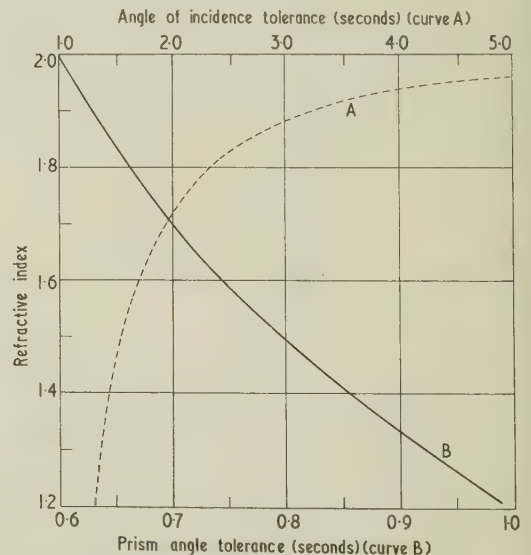


Fig. 4. Curve A, Tolerance on the measurement of the angle of incidence for an accuracy of 0.00001 in the refractive index; Curve B, Tolerance on the measurement of the 30° prism angle for an accuracy of 0.00001 in the refractive index.

(e B). In obtaining the results shown in the Table the angles of the 30° prisms were measured on the 1 Watts goniometer since the method of closing the circle could be applied thereby giving an accuracy of measurement better than $\frac{1}{2}$ second. Using the present angular measuring system an accuracy to ± 5 seconds was anticipated and this would therefore have meant an overall accuracy in refractive index to ± 0.00003 .

A further factor which affects the accuracy of the results is the accuracy with which the wavelengths of the spectral lines are known. Fig. 5 shows the change of wavelength

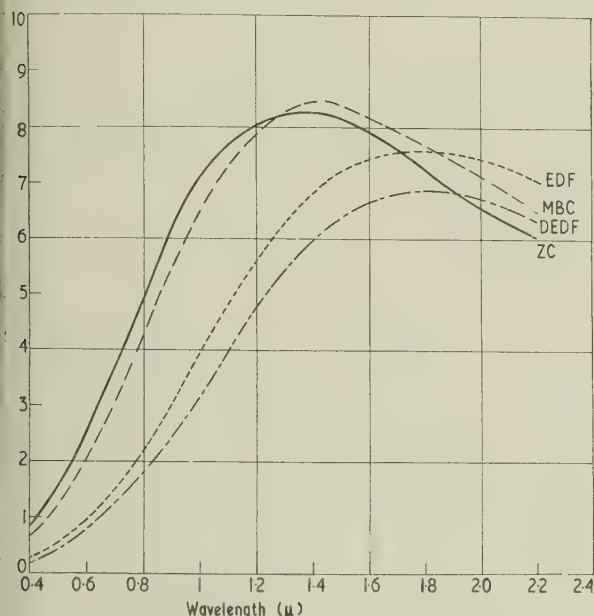


Fig. 5. Change of wavelength corresponding to a change of 0.0001 in the refractive index, for a range of optical glasses between 0.4 and 2.2 μ .

necessary to change the value of the refractive index by 0.0001 over a wide spectral range for a number of optical glasses. Thus for an EDF glass an error of $\frac{1}{2}$ Å in defining the true wavelength of the radiation used at 0.5 μ would

cause an error of 0.00001 in the quoted refractive index, whilst at 2.0 μ an error of $7\frac{1}{2}$ Å is necessary to cause a similar error in index.

In the present instrument a Siemens 125 watt MB/D high pressure mercury lamp was used in order to obtain sufficient intensity in the weaker lines from 1.5 μ to 2.3 μ and the possibility of significant shifts of wavelengths in this lamp has led us to investigate the magnitude of this effect. This was achieved by mounting a diffraction grating on the circular table in place of a test prism so that on rotating the table in the usual manner a spectrum was obtained of the required long wavelength spectral lines with higher orders of shorter infra-red and visible lines superimposed. From spectra obtained in this way the wavelengths of the desired lines were determined and compared with the results quoted by Plyler and Peters (1950). For the optical glasses shown in Fig. 5 the shifts so determined were insignificant compared with the shifts necessary to modify the refractive index by 0.00001 and no corrections were necessary.

6. Results

The Table shows the results obtained for six optical glasses. Originally 60° prisms were made and measured in the visible region of the spectrum on the Guild Watts goniometer to an accuracy of ± 0.000005 . From these prisms 30° Littrow prisms were made and measured in the manner described. The values of the refractive indices for the lines in the visible spectrum agreed in all cases to within ± 0.00002 . The values of the refractive indices for the lines outside this region are believed to be accurate to ± 0.00003 .

7. Further work

Modifications have been made to the instrument to enable measurements to be made to 2100 Å in the ultra-violet, and to 5.0 μ in the infra-red. Refractive indices for some materials in these regions have already been obtained and will be published shortly. In addition, a new goniometer is being made using a radial grating of higher precision and with more lines, with which an accuracy in refractive index to ± 0.00001 is expected.

Refractive indices of some Chance optical glasses at 20° C

Wavelength (Å)	Z.C. CPR 32	L.B.C. 38847	M.B.C. 30519	D.F. 38793	E.D.F. 36689	D.E.D.F. 42266
3663.3 Hg	1.52751	1.56386	1.59633	1.64752	1.76355	—
4046.6 Hg	1.52147	1.55711	1.58887	1.63379	1.74204	1.81192
4358.4 Hg	1.51778	1.55298	1.58435	1.62581	1.72993	1.79625
5460.7 Hg	1.50955	1.54386	1.57437	1.60915	1.70526	1.76532
5875.9 He	1.50759	1.54170	1.57201	1.60537	1.69982	1.75861
7065.2 He	1.50356	1.53735	1.56724	1.59808	1.68948	1.74600
7800.2 Rb	1.50182	1.53551	1.56524	1.59512	1.68534	1.74103
7947.6 Rb	1.50151	1.53517	1.56490	1.59460	1.68465	1.74020
8521.1 Cs	1.50043	1.53405	1.56365	1.59284	1.68227	1.73731
8943.5 Cs	1.49970	1.53328	1.56284	1.59171	1.68075	1.73552
10140 Hg	1.49788	1.53149	1.56087	1.58908	1.67731	1.73144
11287 Hg	1.49635	1.53001	1.55926	1.58706	1.67478	1.72846
13951 Hg	1.49308	1.52701	1.55590	1.58325	1.67031	1.72330
15295 Hg	1.49143	1.52554	1.55435	1.58154	1.66841	1.72115
18131 Hg	1.48773	1.52234	1.55080	1.57796	1.66466	1.71693
19701 Hg	1.48546	1.52040	1.54867	1.57589	1.66256	1.71463
20581 He	1.48411	1.51929	1.54743	1.57469	1.66137	1.71332
23254 Hg	1.47968	1.51559	1.54333	1.57082	1.65759	1.70912

Accuracy ± 0.00003

Acknowledgments

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New Books

Transistor circuit analysis. By M. V. JOYCE and K. K. CLARKE. (Reading, Massachusetts: Addison-Wesley, 1961.) Pp. xiv + 461. Price 81s.

This addition to the considerable existing literature on transistor circuit analysis outshines many of its predecessors in breadth of coverage, clarity of presentation and up-to-dateness. Almost all important topics in the field—and some related ones such as controlled rectifiers and tunnel diodes—are treated in an illuminating way. The authors have endeavoured to provide real insight into the problems of circuit design and their solution, rather than merely to present a mass of circuits, design data and formulae. Thus the mathematics required is very modest, except perhaps for the pole-zero concept, though even this is employed as a descriptive rather than analytical tool.

In contrast with valves, a proper appreciation of transistor circuits depends on a thorough grounding in the physics of the device itself, and herein lies the main flaw of the present volume. This aspect of the subject is covered at break-neck speed in the 25 pages of Chapter 1 and in one or two paragraphs elsewhere; such compression, we feel, must cause confusion in the mind of the student, as it has led to serious errors in the text. Fig. 1-2, for example, actually shows carrier densities close to a reverse-biased junction and not a junction in equilibrium, as stated. Also, why are three different values quoted on pages 2, 4 and 10 for $n_i = p_i$ in silicon at 300°K ? Again, the transport factor calculation at the foot of page 15 is wrong and should read "... $\text{sech}(3/12) = 0.9696$ ". Then, on page 224, it is implied that the parallel-plate analogy for depletion-layer capacitance is valid only for graded junctions; in fact it holds equally for the alloy type. The only effect of charge asymmetry is to bring one 'plate' much nearer the junction than the other.

Chapters 2 and 3, both models of clear exposition, deal respectively with transistor equivalent networks and biasing. The first is commended for its omission of y and z parameters, which avoids confronting the student at the outset with the customary baffling arrays of transformations, usually tabulated with the pages turned sideways! Instead the approach is lucid and practical, with emphasis on manipulation of circuits rather than equations, so that the reader acquires the 'feel'

of various configurations. Chapter 3 is notable for introduction on 'how not to bias a transistor', a thorough treatment of temperature effects and how to overcome them, and for an interesting analysis of thermal runaway, a problem rarely discussed in textbooks. The next three chapters dealing with l.f. and power amplifiers and regulated supplies are largely applications of earlier bookwork but contain much useful information.

Chapter 7, in which high-frequency effects are first introduced, is slightly disappointing, because the account of frequency dependence of α is sketchy and the treatment of noise leaves much to be desired in practical accuracy (it may not be the authors' fault). Following chapters consider wide-band and band-pass amplifiers; the emphasis in both on frequency characteristics, with little said about pulse response.

Transistor switching is discussed in Chapter 10 with the aid of an instructive excess charge model, which includes a 'current source' to represent any built-in field. Unfortunately this element is soon dropped, so that we learn little about saturation or storage in graded-base transistors. However, judging by the modest claims on page 314, the authors apparently have not realized that for d.c. their model is an exact representation of a diffusion transistor, a fact which is evident from the ensuing results. The reason is that the three-dimensional distributed 'resistance' network appropriate to this case is equivalent to a lumped network of three resistors. Only when 'capacitors' are added, to permit transient calculations, does the lumped model become approximate. Various trigger circuits, including blocking oscillator and linear sweeps, are described in the succeeding four chapters, the aim being to provide detailed analysis of a few basic types rather than an encyclopaedic résumé of all possible configurations. The book concludes with useful discussions of negative-resistance devices, oscillators and general active networks.

Homework problems follow each chapter, answers to most appearing at the end of the book, while the references are noteworthy for the frequent addition of useful summaries and comments by the present authors. Altogether, this volume should prove of lasting value to students and engineers alike.

M. O. DEIGHTON

Humidity control device for the Buerger precession camera

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Abstract

A device has been designed and built to maintain a crystal in equilibrium with an atmosphere of constant relative humidity during x-ray photography with the Buerger precession camera. The device employs a small constant-temperature enclosure, mounted directly on the goniometer of the camera. A resistance-wire winding is used to supply a small amount of heat to the enclosure. The temperature is maintained constant by a thermistor-controlled electronic circuit. Temperature control is not interrupted during adjustments to the goniometer head nor is the film changed.

1. Introduction

THE device described in this paper was designed to maintain a crystal in equilibrium with an atmosphere of fixed relative humidity during x-ray photography with the Buerger precession camera. The particular purpose for which this device was built in this laboratory was the investigation of the shrinkage stages of protein crystals. When a protein crystal, grown from aqueous solution, is removed from its mother liquor into the air, it loses water and the crystal shrinks. When it is in equilibrium with its mother liquor, the crystal is in the 'wet' form. The 'air-dried' form of the crystal (a rather ambiguous term) is that form content to prolonged exposure to the atmosphere of the laboratory. Crystals of some proteins have been shown to exhibit several discontinuous lattice changes on drying from wet to the air-dried state (Huxley and Kendrew 1953, Drenth 1957, Einstein and Low 1961). That is, if the relative humidity of the atmosphere with which the crystal is in contact is reduced in a controlled manner, several discrete shrinkage stages may be observed.

In this device, as in those of the other investigators cited previously, the relative humidity is controlled by means of an aqueous salt solution of known vapour pressure, both crystal and solution being kept at the same (or nearly the same) fixed temperature. With a series of saturated solutions of various vapour pressures it is possible to cover at fairly small intervals the entire range of relative humidity (O'Brien 1948).

In the device of Huxley and Kendrew (1953) the temperature was controlled by the use of a double-walled enclosure, surrounding the entire camera and provided with a cellophane window which admits the x-ray beam. Water from a thermostatically controlled bath is circulated between the walls. This device has the advantages of interchangeability of enclosures and of unrestricted use of any camera. However, it is necessary to open the lid of the enclosure to adjust the camera setting and/or to change the film. This interruption of temperature control may be a disadvantage in the case of studying an unstable shrinkage stage, especially if the crystal must be reset after shrinkage. In his device, Drenth (1957)

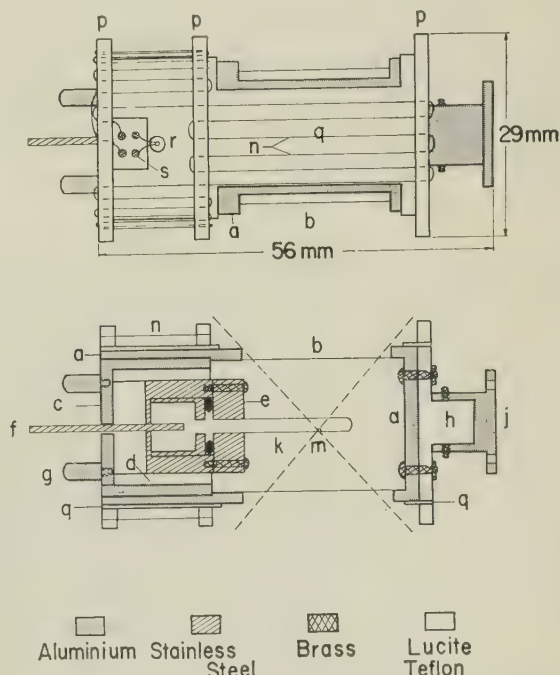
employed a double-walled sleeve; this fits over the crystal and the goniometer head, and is provided with two cellophane windows. Water from a thermostatically controlled bath is circulated through the jacket. The device does not permit use of the full (30°) range of precession angle of the camera.

In the operation of the device described here, temperature control is maintained at all times, even during crystal adjustment or film changing. This is made possible by the use of a very small, light-weight enclosure, which is attached directly to the goniometer head. The temperature is controlled by means of an electrical heater winding and thermistor-actuated electronic thermostat. The full range of precession angle of the camera may be employed if the crystal is properly mounted.

An earlier model of the device described here was used extensively in shrinkage studies of insulin crystals (Einstein and Low 1961). The older model was the same in principle but differed in some minor constructional details.

2. Construction

The enclosure (see Figure) is an aluminium tube *a* with rectangular windows *b* and one open end (at left in Figure).



Top. Top view of device, showing heating element, thermistor, and terminals.

Bottom. Horizontal section of device through cylindrical axis of enclosure.

The aluminium cell-holder *c* fits into and closes the open end of the enclosure. The windows are of Mylar, 0.00025 in. thick. A Teflon lining *d* inside the cell-holder holds the cell *e* by friction fit. The cell-holder has a small hole to allow a stainless steel capillary tube *f* soldered to the cell to protrude out of the enclosure. The cell-holder may be rotated within the enclosure by means of its two pins *g*. The angle of rotation may be measured by divisions engraved at 5° intervals on the end of the cell-holder. The enclosure is attached to a Teflon flange *h*, which is fixed to the goniometer head by means of a small aluminium adapter *j*. The flange insulates the enclosure somewhat from the colder goniometer head. The unheated outer face of the cell-holder is covered with a styrofoam cap (not shown in the Figure) to reduce the loss of heat.

The cell is of stainless steel. Its lid, which is provided with a hole for the glass capillary *k*, is fastened on with four screws, two of which are shown in the Figure. The crystal is mounted at *m*. The cell is sealed by an O-ring, which is supported by a spacer. The stainless steel capillary tube is soldered into the end of the cell so that it protrudes 4 mm into the cell and 16 mm out of the cell.

A resistance-wire heating element *n* is wound through holes in three lucite rings *p* which are cemented to a thin lucite tube *q*. The tube fits the enclosure snugly and has windows of appropriate size. The heating element is covered with aluminium foil backed with cellophane tape (not shown in the Figure).

The bead thermistor *r* is mounted with cement in a small screw, which screws into the wall of the enclosure. (A hole for the screw is provided in the lucite tube.) Leads for the thermistor and the heating element are attached to four terminals *s* made of thin brass rod. The terminals are held in a small section of a lucite ring cemented to the lucite tube. The electronic controller used in this laboratory was the Thermistemp temperature controller, model 63RB (by the Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio). This is an 'arbitrary-set' controller which may easily be calibrated for a small range of temperature, including the normal operating temperature 25° C. The thermistor used was a Veco No. 25A5 (by the Victory Engineering Corporation, Union, N.J.). Any equivalent combination of bead thermistor and controller might be used.

3. Operation

A thin-walled glass capillary is sealed with wax into the hole in the lid of the cell, so that it opens into the cell; the other end of the capillary is sealed off with a flame. The wet crystal is mounted in the capillary. A small amount of mother liquor is then placed in the cell, the lid screwed on, and the cell mounted in the enclosure, which is attached to the goniometer head of the camera. The crystal is aligned initially while it is wet. This may involve re-orienting it on the wall of the capillary (see Section 4). The cell is then removed from the enclosure and opened. The mother liquor is replaced by saturated salt solution (at 25° C) and a few small crystals of salt. Excess liquid adhering to the capillary walls and to the crystal is then removed, and the lid is screwed back on to the cell. The cell is then replaced in the enclosure, which has remained on the camera, and which has been brought to the operating temperature (normally 25° C). Time is allowed for the contents of the enclosure to come to thermal equilibrium.

The cell and glass capillary are then partially evacuated through the steel capillary tube by an aspirator. The purpose

of evacuation is to accelerate the equilibration of the crystal with the salt solution. The cell is connected to the aspirator by a series of interconnecting tubes in the following order: cell, polyethylene tubing, brass adapter, pressure tubing, glass tubing (provided with stopcock), pressure tubing, aspirator. One end of the brass adapter is a hollow tube of the same outside diameter as that of the steel capillary tube projecting out of the cell. The other end of the adapter fits snugly into the pressure tubing. A short length of polyethylene capillary tubing of appropriate inner diameter is used to connect the steel tube to the brass adapter. The adapter is positioned so that the ends of the two metal tubes abut against each other. This is done so that the polyethylene tubing will not be crimped by atmospheric pressure when it is evacuated.

The line between the cell and the stopcock—brass adapter, pressure tubing and glass tubing—is heated by a heating tape so that water vapour from the cell will not tend to condense there, but will remain inside the cell.

A period of about an hour is allowed for the contents of the enclosure to come to thermal equilibrium. During this time the stopcock in the glass tube is closed. Then the stopcock is opened, and the aspirator turned on. As soon as vacuum has been established, the stopcock is closed; otherwise, the salt solution in the cell would dry up. After x-ray photographs have shown that the required shrinkage process is complete, dry air is introduced into the system, the polyethylene tube is slipped off the steel tube (or cut with a razor) and the tube is sealed.

4. Crystal alignment

It is desirable to avoid unnecessary restriction of the values of the parameters μ and ν , which might be caused by the interception of the incident or diffracted beams by the edges of the windows. (The parameters are defined: μ = precession angle, ν = semi-vertical angle of the cone with apex at the crystal, produced through the circle of intersection of the sphere of reflection with the *n*-level reciprocal-lattice plane being photographed.) Therefore, the line joining the midpoints of the windows (hereinafter called the 'window axis') should make as small an angle as possible with the normal to the reciprocal-lattice plane being photographed. Further, the crystal should lie on the window axis. The latter requirement may be met by proper mounting of the crystal in the capillary, and by insertion of the cell into the cell-holder to the proper depth. There are several millimetres of play in the latter adjustment.

With the crystal on the window axis, and the normal to the reciprocal-lattice plane parallel to the window axis, maximum values of about 40° for the parameters μ and ν are permitted by the window size. The dashed lines in the lower drawing of the Figure show the angle allowed by the windows in the horizontal plane; the angle in the vertical plane is the same. An alignment procedure for attaining maximum values for these parameters is the following. First, with $\mu = 0$, the window axis is set collinear with the incident beam direction. Adjustments necessary to align the crystal are then made as follows. (a) The crystal may be rotated about the incident beam direction using one goniometer arc; this does not restrict μ or ν . (b) It may be rotated about the dial (or spindle) axis by turning the cell-holder within the enclosure; the camera dial is used for final (<2°) accurate adjustments. (c) Rotation about the vertical axis must be done with the other goniometer arc; the maximum permitted values of μ and ν are decreased by the angle of this adjustment. Adjustments of the last kind should therefore be avoided to as large an

ent as possible by the proper orientation of the wet crystal the wall of the capillary tube.

5. Collection of three-dimensional data

The main purpose for which this device was designed was recording of zero-level photographs; these may be obtained with the maximum (30°) precession angle of the camera. It is possible to collect three-dimensional data only at moderate resolution because of the restriction of the parameter ν , and, in the case of protein crystals, because of the restricted choice of reciprocal-lattice planes to those widely-spaced planes which can be resolved with screens. (In this laboratory, screens of annular width 2.5 mm were used.) In the case of a protein crystal having lattice dimensions of the order of 50 Å, with favourable crystal habit and space group, complete three-dimensional data could be collected to a resolution of 4–6 Å, using CuK_α radiation.

Acknowledgments

I wish to thank Professor Barbara W. Low, who suggested this research problem, for her continued interest during the course of the work, Mr. F. Sellmer for many helpful suggestions in the design of the instrument and Mr. L. V. Singman who prepared the Figure.

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New Books

Messen mit elektrischen Geräten. Grundlagen und Anwendungen. By H. NEUMANN. (Berlin: Springer-Verlag, 1960.) Pp. xii + 640. Price DM. 55.50.

This book deals with electrical measurements of many kinds from an electrotechnical point of view: it does not cover electronic apparatus (except the cathode-ray oscillograph) or the use of electrical devices for non-electrical measurement. There is detailed constructional and theoretical information about indicating, recording, and integrating meters, about instrument transformers, and potentiometer and bridge methods. In accordance with the general bias of this book electrostatic and thermal instruments receive brief treatment; a few technically interesting devices such as maximum demand recorders and the transformer-arm bridge are omitted for no apparent reason. There is, however, a short and interesting section on the exploration of electrostatic and magnetic fields. Examples of technical practice and standards of performance are entirely German. Within these limits the book contains much information, and as usual with the Springer firm the technical standard of book production is extremely high.

H. J. J. BRADDICK.

Textures in metal sheets. By F. A. UNDERWOOD. (London: Macdonald, 1961.) Pp. xii + 148. Price 28s.

One of the major technological triumphs of x-ray diffraction is the elucidation of the problems involved in fabricating metals. This book describes these and describes also the operations involved in the process. The book should be of great help to beginners, introducing them to the subject.

pH measurement and titration. By G. MATTOCK with a chapter by G. ROSS TAYLOR. (London: Heywood, 1961.) Pp. xiv + 406. Price 63s.

Gas chromatography. A Symposium held under the auspices of the Analysis Instrumentation Division of the Instrument Society of America, June, 1959. Editors H. J. Noebels, R. F. Wall, N. Brenner. (New York, London: Academic Press, 1961.) Pp. xvi + 463. Price 114s. 6d.

The book contains over 30 papers given at the Second International Symposium on Gas Chromatography. The papers are mainly experimental in nature, but a few theoretical papers are included.

Heat cycling apparatus for thermostat testing

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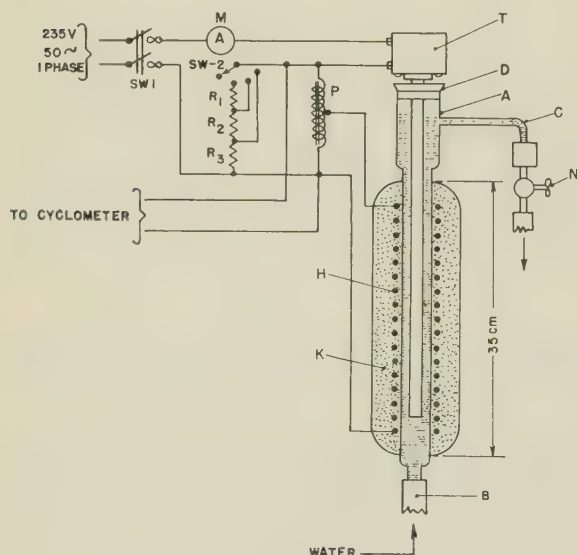
MS. received 8th August 1961

Abstract. An apparatus using a water flow method, has been described for giving the heat cycles necessary for testing the switching performance of thermostats, according to B.S. 1555.

One of the main requirements of any thermostat is that for the specified contact current it should be able to perform efficiently for a very long time. A destructive type of test has been prescribed for this purpose in B.S. 1555. It specifies that (B.S. 1555: 1949, Clause 6(c)) after fifty thousand thermally operated, consecutive switching cycles at full load current, the temperature differential of the thermostat should not change by more than the prescribed amount. According to this standard, the test should not be performed at a rate greater than 250 cycles per hour.

Carlebach (1953) has described an arrangement for these heat cycles. The stem of the thermostat is heated as a resistance element and intermittently cooled by a water spray. This requires three or four electromagnets besides a rather complicated water spray system. Moreover, the method of heating the thermostat differs very much from the actual working conditions.

A somewhat simpler arrangement, shown in the Figure,



Heat cycling apparatus for thermostats. A, Pyrex tube; B, water inlet; C, water outlet; D, cork; H, 18 s.w.g. 4.5 ohm Nichrome heater; K, moulded asbestos insulation; M, 0-30 A a.c. ammeter; N, needle cock; P, 7 kva auto-transformer; R₁, R₂, R₃, Nichrome resistances; SW-1, 30 A main switch; SW-2, 30 A regulator switch; T, thermostat under test.

has been adopted for this purpose at the National Physical Laboratory of India. The thermostat T is fitted watertight into a wide mouthed Pyrex tube A, through cork D as shown. The narrow portion of the tube is wound with an 18 s.w.g. Nichrome (Driver Harris) heater H, of 4.5 ohm cold resis-

tance, and insulated with moulded asbestos insulation. The heater H is fed from an auto-transformer P through 30 A ammeter and through the contacts of the thermostat under test. Normally the working current of the heater is such that the mains current of the auto-transformer is 5 A. A rotary switch SW-2 connects combinations of resistors R₁, R₂, R₃ in parallel with the auto-transformer. The resistors are such that the thermostat contact current can be made 5, 10, 15 or 20 A by adjusting SW-2. This corresponds to the four current ratings of thermostats recognized by the B.S. 1555.

The inlet B of the Pyrex tube A is connected to water main and its outlet C discharges the water through a needle cock N (Bansal and Srivastava 1960, 1961). Since this apparatus has to work round the clock, a closed circuit water supply system was considered economical although it is not shown in the diagram. The discharged water was collected in a tank from where it was occasionally pumped back into the tube automatically, with the help of a water level controller (Bansal 1961).

In actual operation, the temperature of the water flowing through the apparatus gradually rises, opening the thermostat contacts. As the flowing water cools down, the thermostat switches on the heater again. This heat cycle repeats itself automatically as it would under actual working conditions. The thermostat as well as the apparatus would remain unharmed by breakdowns of water and/or electric supply. The former results in considerable reduction of operating frequency while the latter shuts down the whole test.

Although the needle cock could be adjusted for the maximum prescribed operation frequency of 250 heat cycles per hour, it was found convenient to limit it to about 150 only. A 235 v a.c. operated electromagnetic counter, or cyclometer, was connected across the auto-transformer P for counting the number of operations performed by the thermostat. The cyclometer does not operate if the thermostat contacts happen to short circuit or if they open circuit due to a complete burn out. The apparatus remained undamaged in a 24 hour run after the thermostat contacts had short circuited and water supply had failed, so additional safety precautions were considered unnecessary.

Acknowledgments

This work was taken up as part of a research programme in testing. We are grateful to the Director, National Physical Laboratory of India, for providing the necessary facilities and for permission to publish this note.

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Improved reflection diffraction holder for electron microscope

J. C. HENDERSON, B.Sc., G.P.O. Research Station, Dollis Hill, London, N.W.2

received 12th June 1961

conventional reflection diffraction holder for use with the microscop 1A electron microscope (by Siemens and Halske) employs a screw clamp to hold the specimen, so that the electron beam strikes the surface to be investigated at grazing incidence. Considerable dismantling of the microscope column is necessary when changing from transmission studies to reflection diffraction using this holder, e.g. the objective lens, e-pieces and aperture holders must be removed and the electron gun assembly angled to give the optimum illumination of the specimen.

If, however, the holder provided for stereo transmission is modified as shown in the Figure, then transmission and

is no longer necessary and much time is saved in not having to realign the column. The angle of incidence can now be adjusted by means of the stereo drive; additionally, since the objective lens can still be used, shadowgraphs of small asperities on the surface can be viewed in detail and related to particular diffraction patterns obtained from these areas.

The Figure shows that the modifications to the conventional stereo holder are confined to part A (part B remains unchanged). Part A can be substituted for the movable part of the original transmission holder because it has essentially the same profile and similar external dimensions. It should be noted that all components of part A (as well as those of part B) are of non-magnetic material.

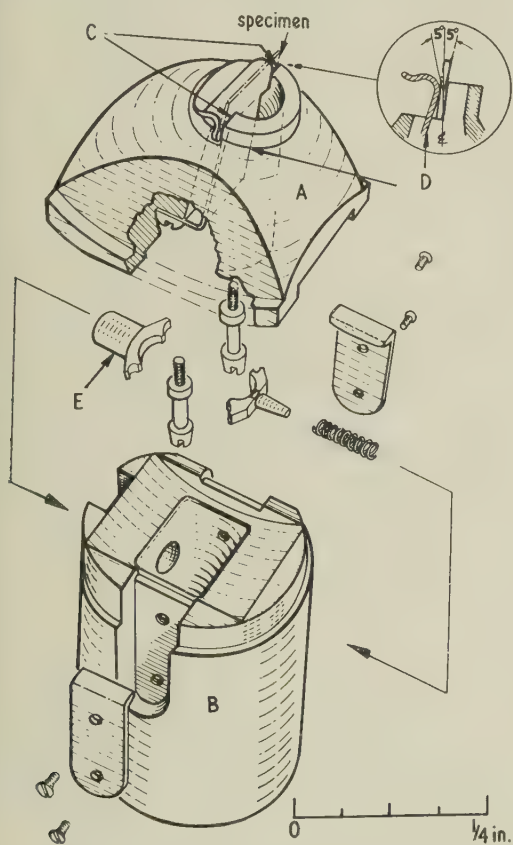
The specimen, in the form of a plate about 3 mm $\times$ 2 mm in area and up to about 1 mm thick is held against the brass shoulders C by a phosphor-bronze spring clip D; easy removal of the specimen is thus possible with the minimum of handling. The stereo drive assembly in the microscope column bears against the yoke E, and is capable of tilting the specimen holder A $\pm 5^\circ$ relative to the electron beam to give the required angle of incidence.

The procedure adopted for estimating, approximately, the appropriate tilt of the specimen in order to give a diffraction pattern from the surface was to focus the objective lens on to the edge nearest the electron beam, and to view the resulting shadowgraph whilst tilting the specimen by means of the stereo drive. Because the front and back edges of the specimen are in different planes, the magnetic lens causes the shadow of the back edge to be rotated relative to that of the front. The rotation provides a sensitive means of detecting the position of grazing incidence, because in this position the shadow of the back edge appears to rise at an angle above the horizon provided by the shadow of the front edge. When the shadow of both the front and back edges became visible, the objective lens was switched out and only minor adjustments to the stereo drive were necessary to give good diffraction patterns on the final screen.

The new holder is being used successfully to study the surface of single crystals of silicon during various stages of transistor fabrication.

The author wishes to thank his colleagues at the Post Office Research Station for many helpful discussions and, in particular, Mr. J. C. North for proving the suitability of the design. He acknowledges the permission of the Engineer-in-Chief of the British Post Office to make use of the information contained in this note.

Reflection diffraction studies can be alternated at will merely by interchanging specimen holders; dismantling of the column



New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep her informed of their new or improved products. The Institute of Physics and The Physical Society assumes no responsibility for the statements given below; information for these has been taken from literature supplied.

A.C. converter voltmeter type LM 903. Solartron Laboratory Instruments Ltd., Cox Lane, Chessington, Surrey.

The Solartron a.c. converter voltmeter measures a.c. voltages (0–500 v) over the frequency range 20 c/s to 5 Mc/s. It was designed primarily to operate in conjunction with the Solartron digital voltmeter LM 902.2 to give 4-figure digital display of a.c. voltages from 100 μ v to 500 v (in five ranges). The measuring accuracy, when so used, is to $\pm 0.25\%$ (50 c/s–100 kc/s) and to $\pm 2\%$ (20 c/s–750 kc/s) of full scale on each range, with useful indications up to 5 Mc/s. Operating alone the a.c. converter voltmeter covers 0–15 mv to 0–500 v in ten ranges, with measuring accuracy to $\pm 2\%$ on the built-in meter. The input impedance is 1 M Ω shunted by approximately 40 pF. Fine pre-set controls and an internal calibration voltage permit accurate initial setting of the instrument prior to being used either on its own or with the digital voltmeter. A coaxial socket permits monitoring of the amplified a.c. signal on an oscilloscope. Although supplied as bench units, the a.c. converter and digital voltmeter are easily adapted for standard rack mounting. Mains input 100/200 v $\pm$ 5, 10, 20 v, 50–60 c/s.

f-C meter type MM 1009. Solartron Laboratory Instruments Ltd., Cox Lane, Chessington, Surrey.

This portable, battery powdered f-C meter type MM 1009 gives direct readings of frequency (0–100 c/s to 0–100 kc/s) and capacitance (0–1000 pF to 0–0.3 μ F). As a frequency meter it has a $\pm 3\%$ measuring accuracy on five ranges up to 10 kc/s and $\pm 5\%$ on the two ranges above, these accuracies holding for a 2:1 spread in mark/space ratio. The input signal (100 mv–150 v r.m.s. amplitude) is limited and fed into a pulse counting type integrator circuit. With a suitable input transducer this direct reading frequency meter could be adapted for numerous applications in tachometry. As a capacity meter the MM 1009 covers the range 0 to 0.3 μ F in six ranges with accuracy to $\pm 2.5\%$ maintained over the battery range 12 v to 8 v. The unknown capacitor is compared with the internal standard by substitution in the integrator circuit. Suitably chosen standards thus provide accurate direct readings of capacitance. The range is easily extended to 1.0 μ F. It uses semiconductor devices throughout and is powered by eight leakproof U2 cells (International Standard) or equivalent, giving a useful operating life of three months, and weighs 6 lb.

Vacuum gas analyser. Wild-Barfield N.R.C. Model 912. Wild-Barfield Electric Furnaces Ltd., Elecfurn Works, Watford, Herts.

This machine quantitatively determines the amounts of oxygen, nitrogen and hydrogen retained in metals during their refinement. The properties of metals such as the elastic limit and tensile strength are quite often adversely affected by the

presence of such gases and so it is useful to be able to determine the quantity of retained gasses as accurately as possible.

The machine consists of three main parts, a furnace, diffusion pump and an analytical system. The furnace contains a quartz tube in which there is a small graphite crucible, capable of being inductively heated to 2400°C. Evolved gases are transferred from the furnace by diffusion pump either to the analytical system or to atmosphere, as required.

In operation the crucible is heated and the metal sample gives up its gas quantitatively. The oxides react with the graphite crucible and the oxygen is released in the form of carbon monoxide. The hydrides and nitrides are decomposed to liberate hydrogen and nitrogen directly. The resulting mixture of carbon monoxide, hydrogen and nitrogen is pumped out by a transfer pump drawn into a vacuum chamber and thence to a McLeod gauge by the mercury diffusion pump. Gas is isolated in desired parts of the system by means of mercury cut-offs and is circulated through a heated tube of copper oxide where the hydrogen and carbon monoxide are converted into water vapour and carbon dioxide respectively, the nitrogen being unaffected.

Passage of the gas through a cold tube of magnesium perchlorate absorbs the water vapour. The remaining gas is fed through a cold trap at -196°C , where the carbon dioxide is frozen out leaving the nitrogen to return to the McLeod gauge where its pressure is determined. The cold trap is then allowed to rise to room temperature and the pressure of the carbon dioxide which is also transferred to the McLeod gauge and the combined gas are measured. The pressure due to each gas can then be determined using Dalton's law.

In practice, a graph can be plotted showing quantity of gas evolved against time.

The makers claim that the results obtained using this machine are more regular and can be evaluated to finer limits than those obtained using chemical analytical methods.

'Portex' polythene gloves. Portland Plastics Ltd., Knightbridge House, 197 Knightsbridge, S.W.7.

These gloves were designed and intended primarily for medical purposes where their ultra-lightness, and thin texture ensure that no loss of sensitivity to touch is felt by the user. They would also be most useful in the electronic and scientific industries and in all laboratories to ensure protection from corrosion of specialized components or contamination of biological specimens, foodstuffs, etc.

The gloves, which are transparent, are meant to be used only once and then thrown away. This is made possible owing to their extremely low cost (less than 2d. per glove). They are internally dusted with fine talcum for ease of fitting and removal and are in bags of fifty pairs.

E-G meter. Distributors: Aveley Electric Ltd., Ayrton Road, Aveley Industrial Estate, South Ockendon, Essex.

The E-G meter, which is manufactured by Knetz allows rapid and repeatable measurements of the dynamic modulus of elasticity E and the torsional modulus G of solids such as metal, concrete, rock, plastics, wood, coal, ceramics and other rigid materials. This wide range of application is obtained by a simple and rapid operation, while the de-

mination of the instrument gives repeatable measurements within 0.5%.

The dials are directly calibrated in ton/cm^2 and lb/in^2 . Provision for the use of five calibration units and push on selection of ranges greatly speeds up the testing of a large number of samples.

The 10 in long slide-rule dial carries a calibrated scale for common materials, and extra scales for special materials. Accuracy of the instrument is guaranteed by a built-in quartz-crystal controlled oscillator, providing check points on the dial.

The equipment is reliable and self calibrating and is supplied with a pulse-transmitting test-probe and a mounted stable receiving probe to ensure accurate application to test sample. Construction of the instrument is extremely robust and it is suitable for portable use.

Signature transistors. Rauland Corporation, 6001 West Dickens Avenue, Chicago 39, Illinois, U.S.A.

Rauland pnp germanium alloy transistors types R-Z and R-3 measure 0.160 in. $\times$ 0.130 in. and 0.130 in. $\times$ 0.100 in. respectively. Designed for use as audio or IF amplifiers they have a low noise factor of 5 db coupled with a frequency range exceeding 300. They dissipate 30 mw at 25°C and have the following characteristics: alpha cut-off R-Z is 1 Mc/s and R-3 is 2 Mc/s, breakdown voltages are -30 v collector to base or emitter to base and 15 v collector-emitter.

Display oscilloscope. Airmec Ltd., High Wycombe, Bucks.

The type 279 display oscilloscope is designed primarily as an instructional and demonstration instrument for displaying waveforms. A 17 in. cathode-ray tube with a long afterglow (30 s) is fitted. There are X and Y amplifiers each with input terminals on the front panel, and there is also a time base and a beam switch circuit. The beam switch unit incorporates four Y pre-amplifiers each with its own gain and shift controls enabling up to four related waveforms to be shown on the screen at once.

The time-base generator provides sweep speeds continuously variable from one second to one millisecond and is internally synchronized from the Y1 channel.

Variphase strobe unit. Dawe Instruments Ltd., Harlequin Avenue, Brentford, Middlesex.

The Variphase strobe unit type 1208 is designed to provide a 'slow-motion' effect with a stroboscope used primarily for vibration testing. The circuit incorporates a wideband phase-shifter producing a four phase supply with constant output level for any sine-wave between 5 c/s to 5 kc/s. The four phase supply is applied to a continuously variable phase-shifter with a front panel control calibrated linearly from 0 to 360°. In addition to manual control the continuous phase-shifter may be driven by a variable speed electric motor at between 0 and 1.5 rev/s to provide a difference frequency in the range 0-1.5 c/s. The continuously variable phase output is available for external use. The output is also applied to a trigger and frequency divider unit together with an output stage arranged to give either positive or negative output pulses. The frequency divider provides maximum output frequencies of 100 c/s, 250 c/s, 500 c/s, 1 kc/s and 5 kc/s for any input frequency up to 5 kc/s.

Specifications are:—phase shifter output: sine wave at any frequency, amplitude twice input level (max. undistorted

output 30 v r.m.s. into 100 k Ω); stroboscope output: positive 60 v or negative 120 v pulses into 100 k Ω , duration 0.1 ms to 2 ms, maximum frequency determined by divider control. Power requirements are 200-250 v 50 c/s 60 w.

Transistor vibration meter type 1431. Dawe Instruments, Ltd., Brentford, Middlesex.

The instrument comprises a vibration pick-up, a high gain amplifier incorporating integrating and differentiating networks and an adjustable attenuator, together with a direct reading meter. The pick-up supplied is of the moving coil type and gives an output proportional to the velocity of the motion under investigation. The signal from the vibration pick-up is passed through an integrating circuit for displacement measurement, a differentiating circuit for acceleration measurement or directly to the amplifier for velocity measurement. The required characteristic of vibration, either displacement, velocity or acceleration is selected by a three-way switch. An output jack connector to the monitor stage is provided so that the amplified signal can be displayed on a cathode-ray oscilloscope, or used with a suitable analyser to determine the component frequencies of the frequency spectrum of the vibration. The instrument operates from batteries or mains supply. The meter is calibrated in terms of sine wave vibration. Displacement is in six ranges from 0.001 cm to 0.3 cm full-scale deflection, velocity in nine ranges from 0.01 cm/s to 100 cm/s full-scale deflection, and acceleration in five ranges from 300 cm/s^2 to 3000 cm/s^2 full-scale deflection. Frequency range is 5-2000 c/s and accuracy varies between 1% and 10% according to frequency.

Two-stage rotary vacuum pumps. N. G. N. Electrical Ltd., Avenue Parade, Accrington, Lancs.

N.G.N. two-stage rotary vacuum pumps have undergone a considerable amount of re-design to incorporate features which give improved pumping performance and provide facilities for accurately controlling the degree of gas ballast and automatic oil emptying of the pump casing. The most important feature of the new design is in the method of connection of the two stages which results in a pump with which the permanent gas ultimate pressures obtained are generally better than 10^{-4} mm Hg without gas ballast and better than 10^{-3} mm Hg with full gas ballast flow (i.e. 10% of pump capacity). The gas ballast flow is controlled by a needle valve which may be locked in any position, thus ensuring repeatable pumping performance on continuous cycling with condensable gas loads. Pumps are available having speeds of 1, 3 and 6 ft³/min.

Microswitches, series K5. Burgess Products Ltd., Dukes Way, Team Valley, Gateshead 11.

Although small enough to pack easily into an ordinary matchbox, the K5 microswitch is rated at 25 amps/250 volts a.c., 15 amps/440 volts a.c. or 0.5 amp/250 volts d.c. for resistive loads, and at 15 amps/250 volts a.c. for inductive loads. Two types of actuator are available, a cylindrical plunger for applications where the operating force is normal to the switch face, and an internally pivoted wedge for operation by a cam or other device producing a wiping action. Both types of actuator can be depressed flush with the case without affecting the life of the switch. Switches can be supplied with or without a metal mounting frame, and with normally open, normally closed, or changeover contacts. Tab terminals $\frac{1}{8}$ in. wide are provided for 'Faston' connectors.

Notes and comments

Annual Exhibition of Scientific Instruments and Apparatus

The Annual Exhibition of The Institute of Physics and The Physical Society will be held on 15th–19th January, 1962, at the Royal Horticultural Society's Halls, Westminster, London S.W.1. The latest developments in British scientific equipment will be shown.

Further information may be obtained from The Institute of Physics and The Physical Society, 47 Belgrave Square, London S.W.1.

Weizmann Memorial Fellowships 1962–63

The Weizmann Memorial Foundation will shortly elect four Fellows to spend a year in research in the natural sciences at the Weizmann Institute of Science, Rehovoth, Israel, beginning in the autumn of 1962. These Fellowships are intended for scientists with several years of post-doctoral research experience.

Further information may be obtained from the Academic Secretary, The Weizmann Institute of Science, Rehovoth, Israel, and applications must be received not later than 1st December, 1961.

Notes for the Preparation of Papers for the *Journal of Scientific Instruments*

The following instructions refer to the main points which have to be considered in the preparation of a paper for publication, and authors offering papers to the *Journal of Scientific Instruments* for publication are asked to conform to these recommendations.

Manuscripts

Manuscripts should be typed in *double* spacing on paper not wider than 8 in. and not longer than 13 in. Only one side of the paper should be used, and a margin of 1–1½ in. should be left. As alterations in the text cannot be allowed once the paper is set up in type, authors should aim at absolute clarity of meaning and of typing, and should check the typescript carefully before submission. All manuscripts should be submitted in duplicate, and in addition to the fair copies, a set of small copies or prints of the diagrams (not larger than foolscap) must be attached to each MS. (This enables MSS. to be sent to two referees at the same time and so assists rapid publication.)

Abstract. An abstract is printed at the beginning of the paper immediately after the title, name(s) of author(s), and place of employment of author(s). Two extra copies of the 'title and abstract' page are required for the records.

Mathematics. It is not necessary to give detailed derivations of mathematical expressions and formulae in a published paper when the work is straightforward; it is quite sufficient to indicate the method of treatment and the final results.

References. In the text bibliographical references are made by giving the name of the author and the year of publication in brackets, e.g. (Jones 1942), and details are given in the last section, 'References', where the references are arranged in alphabetical order of authors' names and in date order for each author.

Drawings

Drawings should be in Indian ink on tracing cloth, tracing paper or white card, with lettering in soft or blue pencil. Lettering of a size suitable for reduction will be inserted by our draughtsman. The drawings should in general be sufficiently large to allow of reduction in printing, and the lines should therefore be bold; the frame lines of graphs should be slightly finer than those of the plotted curves.

Full details are available in the Institute and Society 'Notes for Authors', obtainable from the Editor and Deputy Secretary, The Institute of Physics and The Physical Society, 1 Lowther Gardens, Prince Consort Road, London S.W.7.

Papers for publication in the *Journal of Scientific Instruments* should be sent to the Editor and Deputy Secretary at the same address.

British Journal of Applied Physics

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NOTES AND NEWS

New books Notes and comments

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International Conference on Components and Materials Held in Electronic Engineering—London, June 1961

THE conference, which was organized by the Electronics and Communications Section and the Measurement and Control Section of The Institution of Electrical Engineers, attracted nearly 1000 delegates from 14 different countries. Emphasis was on developments in electronic components and materials which had taken place since the Institution's Convention on Ferrites in 1956 and the International Symposium on Electronic Components, held under the auspices of the Royal Radar Establishment, Malvern, in 1957.

Valves, transistors and allied devices were excluded, but otherwise the coverage of the papers was wide, comprising over a hundred contributions which were dealt with on the rapporteur system in order to allow adequate time for discussion. The papers were supported by a small exhibition. As Sir Willis Jackson mentioned in his opening address, the aim of the conference was to discuss how best to foster the production and exploitation of materials of special properties, to develop reliable components and to ensure reliable operation of electronic equipment under the extremely severe but short-term demands of Services' use as well as the less arduous but long-term conditions of commercial applications.

Significant among the materials described were microwave ferrites and garnets, lead zirconate titanate ceramics and vacuum-deposited resistive and dielectric films. The role of these films in the construction of conventional resistors and capacitors was adequately described, but there was special interest in their relevance to new assembly techniques in micro-miniature structures. The form which these structures should take, whether stacked wafers of individual components or of complete microcircuits, or integral blocks of semiconductor materials, each processed to comprise a complete functional circuit, will continue to be debated among the experts, but whatever form becomes established will have to bear the seal of a very high degree of reliability.

The supreme need for reliability, in which term is implied uniformity and invariability of characteristics as well as freedom from breakdown, was reflected in the numerous references in many sessions on individual components and constructional techniques as well as in the one entitled 'Reliability and the effects of extreme operating conditions'. Items so covered included the long-term stability of resistors, the mechanism of electrical breakdown in dielectrics and

recent developments in radio-frequency connecting cables to minimize the incidence of irregularities and to ensure satisfactory operation under arduous conditions.

Certain modern methods of component assembly, such as encapsulation and printed wiring have been developed with the dual objectives of achieving a neat and repeatable form of construction, amenable to mass-production, as well as of ensuring a high degree of reliability by protection against adverse environments and by providing easy inspection. These techniques have their own hazards of both chemical and physical origins, the latter including the effects of mechanical shrinkage and of the electrical characteristics of the encapsulant. These aspects were subjects of considerable discussion. A recently introduced constructional technique, the solderless wrapped connection, was shown to be particularly effective; in part it owes its excellent record of reliability to a built-in 'redundancy' as there are effectively two dozen gas-tight pressure joints in each connection.

Whilst the conference was rightly directed towards the future it was not forgotten that circuit designers have to contend with the vagaries of present-day components, such as noise in resistors, after-effects in magnetic materials and the effects of temperature and frequency on capacitors. Other well-known components which attracted one of the largest attendances to the first of two sessions on electro-mechanical devices were relays, plugs and sockets; the second session was devoted to magnetic materials for data storage.

When the proceedings of the conference are published physicists will find their greatest interests in the papers on microwave ferrites, which occupied two full specialist sessions, and on piezoelectric, ferroelectric and dielectric materials (including breakdown phenomena). They will also note the increasing use being made in the electronics industry of thin films for resistors, capacitors and magnetic storage elements. Although physicists are thus busily helping in making components and equipment smaller and smaller they have the satisfaction of knowing that the industry they are serving is of ever-growing importance, as was evinced by the keen interest displayed throughout the week of the conference.

The General Electric Co. Ltd.,
Telecommunications and Engineering
Research Laboratories,
Hirst Research Centre,
Wembley, Middlesex.

P. R. BARDELL

19th September, 1961

Distance measurement by means of a light ray modulated at a microwave frequency

by K. D. FROOME, D.Sc., F.Inst.P., and R. H. BRADSELL, National Physical Laboratory, Teddington, Middlesex

MS. received 26th July 1961

Abstract

The paper describes an experimental equipment (known as the 'N.P.L. Microwave Mekometer') using elliptical polarization modulation of a light beam at 9.4 Gc/s (9400 Mc/s) and intended for the accurate measurement of distances of the order of 50 m. The beam is returned from a distant reflector to the modulator at which the ellipticity is either increased or cancelled. A knowledge of the speed of light and the modulation frequency serves for the derivation of the modulation wavelength; the distance from reflector to modulator is then obtained in terms of the number of modulation wavelengths in it.

1. Introduction

It is well known (Billings 1958, Zheludev and Vlokh 1958) that some crystals of tetragonal scalenohedral symmetry, particularly ammonium dihydrogen phosphate (ADP) and potassium dihydrogen phosphate (KDP), become biaxial and thus birefringent to light transmitted parallel to the optic axis (z axis) when an electric field is applied in the same direction. (This is the so-called Pockels effect (Billings 1958).) The two induced axes lie in a plane at 45° to the x, y axes. Thus if light plane-polarized parallel to the x or y axes is incident upon the crystal in the direction of the z axis, the light emerging from the crystal will be elliptically polarized when an electric field is impressed upon the crystal in the z direction. The degree of ellipticity depends upon the potential difference applied; the direction of rotation of the emergent light vectors depends upon the direction of the applied field. Consequently if the applied electric field is alternating, the emergent light will be elliptically polarized in opposite senses during successive half-cycles of the alternating field.

Of special interest is the frequency range over which this electro-optic effect will function for modulation purposes. In 1946, Mason referred to unpublished measurements of the dielectric constants of ADP at 24 Gc/s, which demonstrated that even at this frequency the dielectric properties of the crystal are substantially the same as at low frequencies. Rushton (1961) has measured the dielectric constants of ADP at 36 Gc/s and again obtained the d.c. values, namely $\epsilon = 14$ along the z axis, $\epsilon = 57$ in the x or y directions. Consequently one may expect ADP to act as a light modulator at frequencies at least as high as 36 Gc/s. Strangely enough, no attempt to establish directly this light-ray modulation effect at any microwave frequency seems to have been made up to the time of the successful N.P.L. experiments, which had their first public demonstration in May 1960. The equipment described in this paper was patented in September 1960 (Patent Application No. 32675) and demonstrated in May 1961. Very recently, and whilst

this paper was in course of preparation, Kaminow (1961) has published a letter describing a successful modulator using KDP at 9.25 Gc/s. His microwave technique is somewhat different from the authors' in that the modulating cavity designed to make use of travelling-wave operation in a relatively long rod of KDP.

A recent Russian paper (Simkin *et al.* 1960) has demonstrated that the nitrobenzene Kerr cell will function as a modulator at 10 Gc/s if sufficient power is available (e.g. 50 kw in the microwave pulse used).

The N.P.L. 'Mekometer' at present operates with 5 kw pulses at 9.4 Gc/s, corresponding to a modulation wavelength of 3.2 cm. To avoid dielectric heating of the ADP crystal, with consequent thermally induced birefringent strains, the pulse length is only about $1.5 \mu\text{s}$ and the repetition frequency is 50 c/s. The elliptically polarized light emerging from the modulating crystal falls upon a distant reflector and this reflected light is returned through the crystal at a second antinode of the microwave field in a direction again parallel to the z axis, whereupon the elliptical polarization will either be enhanced or cancelled, depending upon the direction of rotation of the reflected light field vector relative to the direction of the microwave field. Thus if the distant reflector is continuously displaced relative to the crystal (in a direction parallel to the optic axis), the reflected light after re-traversing the crystal will vary between the elliptically polarized and plane polarized conditions in a cyclic manner, repeating for each displacement of the reflector of amount equivalent to one half-wavelength of the modulation. The elliptically polarized light is discriminated from the plane polarized by means of an analyser so oriented that the plane polarized light is stopped, but some of the elliptically polarized energy is transmitted. The intensity of the light passed by the analyser varies in a cyclic manner as the reflector is moved. It must be appreciated that the beam of light is polarization modulated and *not* intensity modulated while it is in the space between the modulating crystal and the reflector, that is, when traversing the distance to be measured.

2. Experimental details

The microwave source is a 2J42 X-band magnetron capable of a peak pulse output of about 7 kw. The light source is a xenon flash tube operating synchronously with the magnetron pulses. Light from the source is focused into a narrow plane polarized beam (see Fig. 1). This beam of plane polarized light is passed through the z -cut ADP crystal (length 10 mm, width 8 mm, thickness in the z direction 5 mm) mounted in a microwave cavity resonator in such a manner that the direction of the electric field in the cavity is parallel to the incident light; holes cut in opposite sides of the cavity permit

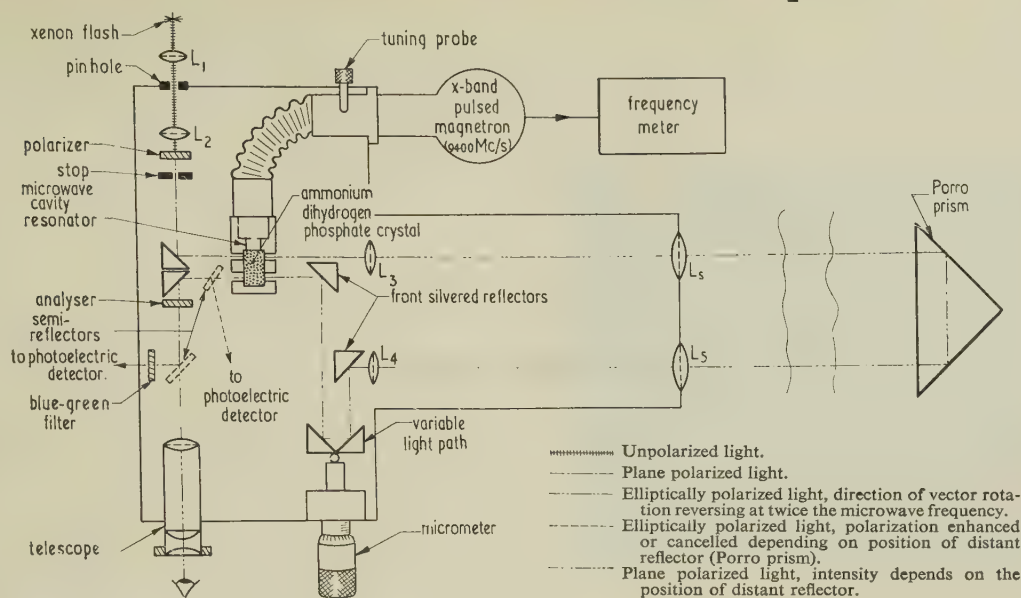


Fig. 1. N.P.L. Microwave Mekometer.

$L_1 = 2$ in. focus
 $L_2 = 5$ in. focus collimating lens

$L_3, L_4 = 16$ mm microscope objective, n.a. 0.12
 $L_5, L_6 = 11$ in. focus objective, $f/10$

entry and exit of the light pencil which is arranged to pass through one of the antinodes of the microwave electric field (i.e. a position of maximum standing electric wave). The light emerging to the right of the ADP crystal is polarization modulated at the microwave frequency. The modulated light beam is rendered parallel by the collimating lens and is projected to the distant reflector, whence it is returned through the system by way of a micrometer-operated variable light path. The returned polarization-modulated light is passed through an adjacent antinode of the electric field in the crystal where the ellipticity is either increased or cancelled depending on the phase of the returned light, and then through the 'crossed' analyser.

It is easy to derive an expression for the variation of light intensity passed by the analyser (and thus seen by the viewing telescope) as the distant reflector is moved.

Consider the elliptically polarized light upon first emergence from the (assumed thin) modulating crystal; this may be regarded as composed of two plane waves of equal amplitude, vibrating in mutually perpendicular planes (each inclined 45° to the incident plane wave), with a phase difference δ which is a function of the appropriate electro-optic constant r_{63} of the ADP crystal (Billings 1958) and the total microwave p.d. applied (V), thus

$$\Gamma_1 = (r_{63}n^3/\lambda_0)V_m \sin \omega_m t \quad (1)$$

where n = ordinary refractive index of the crystal for light wavelength λ_0 , and $V_m \sin \omega_m t$ is the assumed microwave driving voltage of period ω_m .

About 15000 v is required for ADP to produce a $\lambda_0/2$ retardation at very high frequencies. For the experiment described herein the peak microwave voltage applied was limited at under 2000 v.

Let δ (cm) be the difference in length from modulator to reflector over and above an integral number of modulation half-waves; then on passing the light back through the crystal, an additional retardation Γ_2 is introduced between components of the elliptically polarized light

$$\Gamma_2 = \frac{r_{63}n^3V_m}{\lambda_0} \sin \omega_m \left(t + \frac{2\delta}{c} \right) \quad (2)$$

where c is the group velocity of the light in the ambient conditions along its path.

Thus the total relative retardation Γ is given by

$$\vec{\Gamma} = \vec{\Gamma}_1 + \vec{\Gamma}_2$$

$$\Gamma = \frac{2r_{63}n^3}{\lambda_0} V_m \sin \left(\omega_m t + \frac{2\pi\delta}{\lambda_m} \right) \cos \frac{2\pi\delta}{\lambda_m} \quad (3)$$

where λ_m is the modulation wavelength. It will be seen that as the distant reflector is moved, Γ is at a maximum when δ is zero or an integral multiple of $\lambda_m/2$, and at a minimum halfway between successive maxima. The intensity of light transmitted by the 'crossed' analyser is proportional to $\sin^2 \Gamma$ and thus for small values of Γ the intensity will vary in a cosinusoidal squared manner with displacement of the distant reflector. In practice this effect is slightly obscured by the finite thickness of the ADP crystal and by the transmission of the 'crossed' analyser in the absence of incident elliptically polarized light; these produce a flattening of the minima.

In addition to visual observation, the intensity is measured photoelectrically by a bridge system which uses a portion of the polarization modulated light returned through the crystal, but not through the analyser, to back off fluctuations in flash intensity and intensity variations due to perturbations along the path. The output from the photoelectric detector system is electronically processed to produce a direct current, which is displayed on a 50 - 0 - 50 μA meter. The system

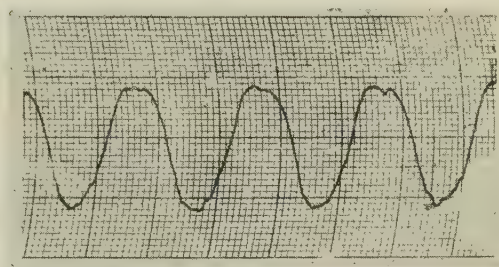


Fig. 2.

can be adjusted so that the zero reading of the meter corresponds to the most sensitive position on the intensity characteristic. Fig. 2 shows a record of the direct current output (intensity) as the distant reflector (situated 50 m from the modulator) was displaced, one cycle representing a half-wavelength (16 mm) displacement of the distant reflector.

Changes in the position of the distant reflector are very precisely detected (to better than 0.1 mm) in this manner. If the distance from the modulating crystal is already known approximately (i.e. to better than a quarter-wavelength of the modulation frequency) it is easy to see how a precision measurement can be made; it is only necessary to introduce such a change (measured by the variable light path micrometer) (see Fig. 1) into the length of the light path as will produce a minimum. The position of the distant reflector for the appropriate detector minimum can be evaluated from the known number of half-waves corresponding to it, the modulation wavelength being obtained from the velocity of light divided by the modulating frequency. If two or more modulation frequencies are used, differing from one another by a few per cent, then the initial distance from the ADP crystal to the distant reflector need be known only very roughly, since then the observed set of 'excess fractions' will only repeat at relatively rare intervals. This method of 'excess fractions' is well known in optical interferometry and need not be discussed here.

The distant reflector at present used is a Porro prism. This is insensitive to yaw but is sensitive to pitch adjustment. It is intended in the future to use a 'cat's-eye' type reflector which will be comparatively insensitive to orientation.

Microwave frequency measurement has been made so far by means of an H_{012} invar cavity resonator of limited tuning range (similar to those used by Essen and Froome (1951) for refractive index measurements on gases). Resonance was detected electronically by means of a diode detector and shock-excited tuned circuit. This 'ringing' circuit is fully described in Section 3. The magnetron was found to be surprisingly stable—its centre frequency could be determined to better than 3 parts per million.

The velocity of light *in vacuo* is known to about 1 part per million (Kaye and Laby 1959), and the group velocity in air can be obtained by dividing by the appropriate refractive index. This is simply determined from measurements of barometric pressure, temperature and humidity along the light path by using Edlén's (1953) formula.

3. Electronic circuits

A block diagram of the electronic circuits is shown in Fig. 3. Figs 4, 5 and 6 show the circuit for the pulse generator, xenon flash and photoelectric detector system respectively.

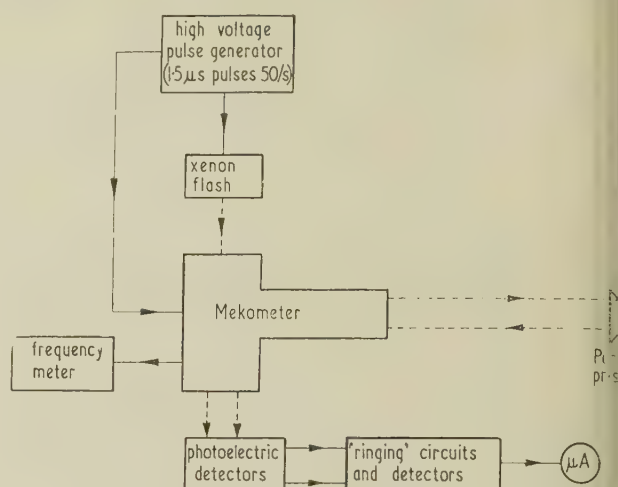


Fig. 3. Block diagram of N.P.L. Microwave Mekometer.

The pulse generator produces negative-going pulses of 1.5 μ s duration and 6 kv peak at a repetition frequency of 50 c/s, and these are fed to the common heater-cathode terminal of a type 2J42 pulsed magnetron.

In Fig. 4, V_1 is a limiting amplifier producing a square wave output from a 50 c/s a.c. mains input. This square wave output is differentiated and rectified to produce positive-going pulses which are fed to the grid of a hydrogen thyatron V_3 . The thyatron is connected as a triggered relaxation oscillator, which produces positive-going pulses of 1.5 μ s duration at its cathode. The output from the thyatron operates the pulse modulator V_4 , which is normally held at a cut-off condition. The high voltage negative-going pulse at its anode provides the h.t. for the magnetron V_5 and also trigger the xenon flash.

Figure 5 gives the circuit for the xenon flash source. The potential across the tube is adjusted so that the flash tube is just at breakdown. The 10 Ω resistor and 0.5 μ H inductor in series with the tube control the flash duration to be close

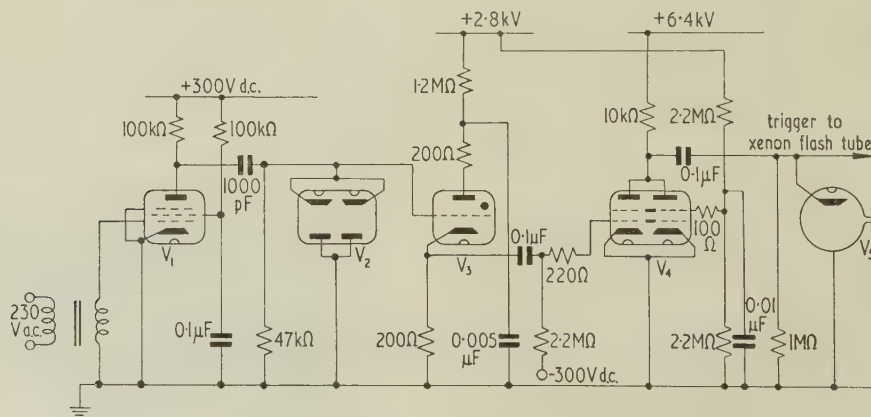
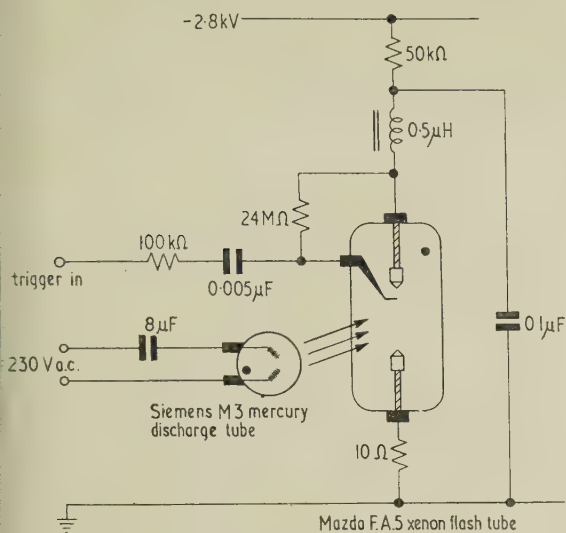


Fig. 4. Circuit diagram of pulse generator.

$V_1 = \text{EF91}$ $V_2 = \text{EB91}$ $V_3 = \text{XH3-045}$ $V_4 = \text{QQV5-P10}$ $V_5 = \text{2J42}$

cathodes, which is proportional to the amplitude of the initial light pulses. RV_2 is a zero-set for the microammeter, which measures the difference in potential between the two detector cathodes.



ures synchronization to $0.1 \mu\text{s}$ when the trigger pulses applied.

The photoelectric detector system is shown in Fig. 6. The two channels each use a photomultiplier (V_1 and V_3) as detector, having a tuned circuit in its anode. These tuned circuits are shock excited by the incoming light pulses and 'ring' at their resonant frequencies. This is shown in Fig. 7(b); the upper trace is the $1.5 \mu\text{s}$ duration light pulse and the lower trace shows the shock excited oscillations. Fig. 7(a) shows the light pulse (upper trace) simultaneously with the sawtooth envelope. The two channels are tuned, in fact, to slightly different frequencies to avoid interaction. V_{2a} and V_{4a} (Fig. 6) are tuned amplifiers operating under Class C conditions. RV_1 is a gain control on the backing-off signal. V_{2b} and V_{4b} are infinite impedance detectors which rectify the trains of oscillations and produce a direct current at their

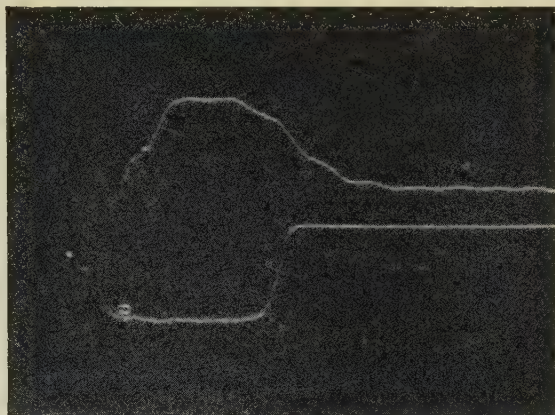


Fig. 7(a).



Fig. 7(b).

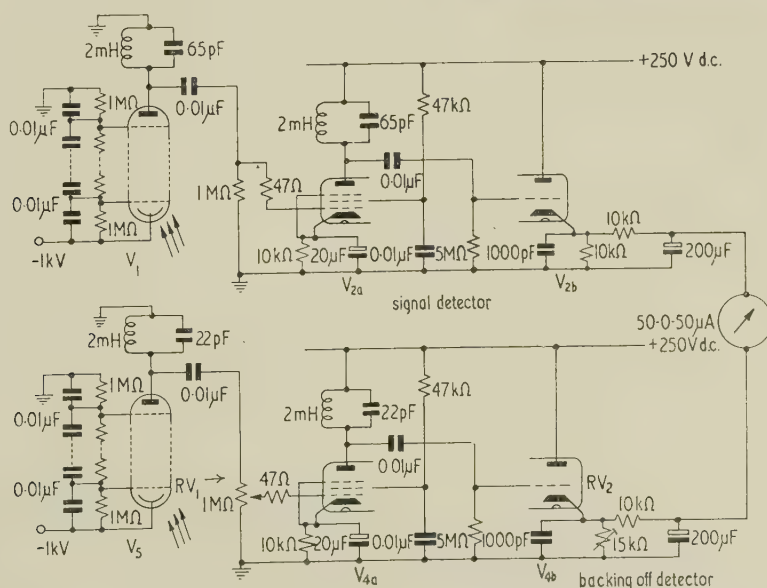


Fig. 6. Circuit diagram of photomultipliers 'ringing' circuits and detectors.

$$V_1 = 931\text{A} \quad V_2 = \text{ECF82} \quad V_3 = 931\text{A} \quad V_4 = \text{ECF82}$$

It has been found that the use of shock-excited tuned circuits to produce a train of pulses from a single pulse is a very potent method of obtaining a useful d.c. output from single pulses of short duration and low repetition rate. These conditions proved necessary to avoid birefringent strain in the ADP crystal due to dielectric heating.

4. Performance

The Microwave Mekometer has been operated at distances up to 50 m under conditions simulating normal sunshine. It was found that at the 50 m distance the instrument was sensitive enough to resolve changes in position of the distant reflector of ± 0.05 mm. The stability of the system is dependent on the frequency stability of the microwave source which, in the case of the pulsed magnetron, is about 3 parts in 10^6 , and including other uncertainties, one part in two hundred thousand is the estimated accuracy of distance measurement obtainable at the present time. It is intended in the future to use a continuous wave klystron local oscillator and a suitable pulsed amplifier as the source. Frequency measurement of a continuous wave klystron to better than 1 part in 10^7 is quite straightforward.

5. Discussion

Geodetic distances of the order of 10–50 km are now regularly measured by means of 'velocity of light' devices. The 'Geodimeter' (Bergstrand 1950) employs a light beam, amplitude modulated at about 10 Mc/s; and the 'Tellurometer' (Wadley 1956) employs a microwave carrier similarly modulated. Since the velocity of electromagnetic waves is known to about 1 part per million (Kaye and Laby 1959), these devices are capable of distance measurement to an accuracy of a few parts per million. The Mekometer is

a device whereby the principle can be extended down to the determination of distances of only a few metres.

The Mekometer also offers a splendid opportunity for further determination of the speed of light, if used in conjunction with the new light wavelength definition of the metre. A distance of, say, 50 m could be measured by optical interferometry, and by the Mekometer, to derive velocity better than 1 in 10^7 .

Acknowledgments

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Robust helical spring microbalance*

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Abstract

An account is given of the construction of a simple nulling microbalance which has been used for low-temperature magnetic susceptibility measurements and may have wider applications.

The device consists essentially of a helical ribbon spiral ring about $\frac{1}{2}$ in. diameter and 12 in. long which supports a working load of about 40 g. The noise level under normal laboratory conditions is less than $2 \mu\text{g}$ and is achieved by mechanical filtering action resulting from a suitable distribution of 20 g of the load. The apparatus is robust, inexpensive and easily constructed.

1. Introduction

A vertical force detector was recently required for some low temperature magnetic susceptibility measurements on transition metals (Coles and Griffiths 1960). While a weighing device for use in such work is no new requirement, none of the existing balances described in the literature is entirely satisfactory in all respects.

Probably the most successful vertical force detectors for this application have been the chemical microbalance, the torsion balance (Hutchinson and Reekie 1946), and the ring balance (Sucksmith 1929). The chemical microbalance can readily sustain heavy Gouy specimens and yet still be sensitive enough for use with small Faraday specimens. Furthermore, it is directly calibrated and relatively free from building vibration troubles. Unfortunately, to prevent gases condensing on the specimen at low temperatures it is necessary that the space surrounding the specimen, and consequently the weighing device, can be completely evacuated before admitting a suitable exchange gas. The chemical microbalance is not very easy to install and operate under vacuum. Moreover, there are large specimen movements which can often make balancing difficult, while eddy currents in low-resistance specimens can make measurements almost impossible unless auto-balancing is used (Hedgcock and Muir 1960). Finally, a good microbalance is expensive and fairly easily damaged. Though conveniently small and easily operated under vacuum, sensitive versions of the torsion balance and Sucksmith ring balance can not carry substantial Gouy specimens, while the ring balance suffers additionally from a considerable sensitivity to building vibration.

2. Gravity meters

It was noticed that gravity meters (Wyckoff 1941, Bruckshaw 1942-3, Heiskanen and Meinesz 1958) have several of the features required by a good susceptibility balance. They are able to detect exceedingly small changes of force in the pre-

sence of large standing values and they are usually of quite small dimensions, so that their temperature may be accurately controlled and they may be easily transported in field use. The Worden meter with its zero length spring is not suitable for unskilled imitation but the Gulf meter design appeared capable of giving satisfactory results, as a balance, even when constructed quite crudely. Interest was also aroused at that time in the curiously shaped springs developed by Tomaschek (1956) for use in borehole gravity meters. Preliminary springs following this pattern were found to be remarkably sensitive but they were rather difficult to control and the Gulf principle was adopted as promising a more manageable device for the present purpose.

The Gulf gravity meter, as developed by the Gulf Research Laboratories, Pittsburgh, consists essentially of a helical spiral ribbon spring supporting at its lower end a load which is typically about 100 g; changes of gravitational acceleration are then detected by measuring the resultant rotation of the lower end of the spiral. An ingenious feature of the design is that the load is distributed so as to have a very large moment of inertia about the vertical axis, resulting in a ratio of rotational period to period of vertical oscillation of about 7 to 1. This arrangement then acts as a mechanical filter giving the rotational deflection a remarkable immunity to ordinary building vibrations.

3. Construction

3.1. Spiral

It was eventually found that a conveniently sized spiral could be made from a $\frac{1}{4}$ in. wide, 0.003 in. thick strip of Elinvar (Ni-Span C, supplied by Henry Wiggin & Co. Ltd.); this material was chosen for its small temperature coefficient of expansion and elastic modulus. When a 24 in. length of this strip was cold-wound by hand round a suitable rod to produce a finished diameter of about $\frac{1}{2}$ in., it was found that such a spiral could support a working load of some 40 g which unwound the spring about 5 turns, giving a working length of about 12 in. The ends of the spiral were turned in by hand, using a fine-nosed pair of pliers, so that small hooks could be soldered centrally to the ends of the spiral. For a 1 mg change in the 40 g load, these spiral dimensions produced a light beam deflection of about 1 mm at 1 m, with a vertical extension of about 2 mm/g increase in load.

3.2. Load and damping

About 20 g of the 40 g load was symmetrically disposed around the spiral axis at a radius of about $3\frac{1}{2}$ cm, as indicated in Fig. 1. With the remainder of the load near the vertical axis, this produced a rotational period of $3\frac{1}{2}$ s and a vertical period of $\frac{1}{2}$ s, a ratio of 7 : 1.

Movements of the spiral were damped by attaching to it three copper disks of about 1 in. diameter and arranging that

* This article includes material from part of a Ph.D. thesis submitted to the University of London.

these should swing closely over three small Eclipse button magnets symmetrically disposed round the spiral axis. Spurious forces can sometimes be produced in such a system

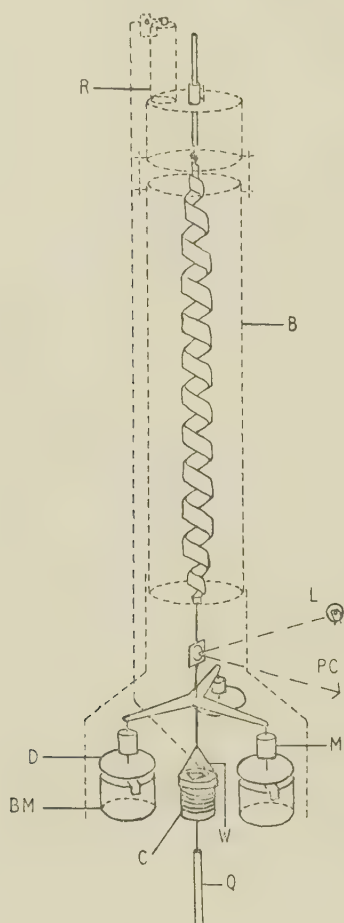


Fig. 1. Basic features of balance. The spiral hangs in brass tube B; three masses M (7 g each) provide required moment of inertia about the vertical axis; damping disks D swing over button magnets BM; restoring coil C hangs in the gap of a small loudspeaker magnet (omitted for clarity) to the rim of which the button magnets are firmly held by natural attraction; spiral rotations are detected by a lamp L and photocell PC arrangement; relay R lowers calibrating weight W; quartz rod Q connects balance to specimen holder. (For clarity the third button magnet is not shown.)

due to ferromagnetic impurities in the disks. Commercial quality copper was used in this case as any such forces would be of no consequence, since it was proposed to use a null method of measuring the force on the specimen.

3.3. Sensitivity and noise level

The rotation of the light beam reflected from the mirror at the bottom of the spiral was detected by a divided cathode selenium photocell, the out-of-balance current being observed on a 230 mm/ μ A, 430 Ω mirror galvanometer. For a 1 mg change in the 40 g spiral load there was a deflection of 350 mm on this galvanometer with a noise level of less than 1 mm peak to peak, i.e. less than $\pm 2 \mu$ g. This noise level corresponded to random deflections of the light beam of about 2×10^{-6} rad which is equivalent to 1 mm deflection at 500 m throw. The theoretical variation of the zero position due to tidal changes in the gravitational acceleration was about

5 times this noise level but the long-term stability of the apparatus was not sufficient for this effect to be observed.

This noise level was originally obtained when the apparatus was bolted to a basement foundation wall in a solidly built brick building. Preliminary measurements with the apparatus reassembled on the seventh floor of a steel-framed building show no significant increase in noise level. Except when the apparatus was actually touched, the only occasion when the noise ever increased occurred when the bells were rung in a neighbouring tower; the motion of the tower caused long period seismic disturbances which increased the noise level by a factor of between 5 and 10.

The deflection sensitivity of an actual Gulf gravity meter spiral is about ten times greater than that of the present simple device and can be read with about a hundred times the accuracy; Wyckoff (1941) quotes a light beam displacement of 0.001 in. at a 22 in. throw for a change in load of 1 part in 10^7 . This sensitivity arises from the considerable negative effective length of the unloaded commercial spring, resulting from a prestressing treatment which makes the spiral curl into a tight bundle when released. The present simple spring only coils up until adjacent turns are nearly touching when the load is removed.

3.4. Force balancing

The force on the specimen was counterbalanced with a simple coil and loudspeaker magnet arrangement; this has a good linearity characteristic. The radial field in the gap of this magnet was about 2 kOe which was enough to mask any effect from the stray field (< 1 Oe) of the main electromagnet. The current calibration of this system was periodically checked against a 100 mg platinum weight which could be lowered by a relay on to a small scale-pan attached to the end of the spiral; the restoring current was passed through a standard resistor R and the resulting voltage measured with a precision potentiometer P (Fig. 2). This restoring system

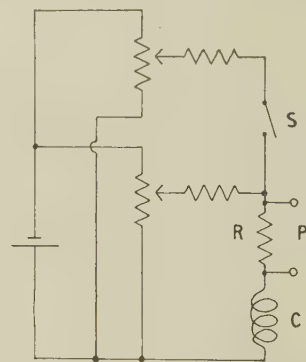


Fig. 2. Restoring current controller.

allowed changes in specimen weight from a fraction of milligram up to 300 mg to be measured with equal facility.

A useful feature of the circuit supplying the restoring current was that it incorporated, in effect, a memory, so that the zero position of the balance could be quickly checked without necessarily altering the setting of the two balancing currents the difference of which gives the force on the specimen. The restoring current, which never exceeded a few milliamps, was supplied by two banks of four potentiometers (Colvern wire wound radio type) connected across an accumulator which then had a nearly constant current drain; one potentiometer of each decade bank is shown in Fig. 2. The lower bank is

manently connected to the restoring coil and is used to the zero position of the light beam on the photocells. Additional forces on the specimen are counterbalanced by itching in the upper bank at a suitable setting. The zero position can then be quickly checked simply by opening switch S, while the two balancing currents can be measured at leisure afterwards. This arrangement proved very convenient in practice.

Although the connecting wire to the restoring coil was brought in close to the spiral axis, it was found that a free hanging 12 in. length of 48 s.w.g. (0.002 in. diameter) copper wire was necessary if the sensitivity of the balance was not to be unduly impaired. This lead-in wire was easily accommodated alongside the spiral which itself served as the return current conductor.

4. Spurious effects

With the present Elinvar material the zero moves by the equivalent of about a $1\frac{1}{2}$ mg change in specimen weight for 1°C change in room temperature, compared with about 1 mg/ $^\circ\text{C}$ for phosphor bronze. The spiral is hung in a stout brass tube which stands on tripod legs on a base plate. The whole assembly is enclosed in a glass cylinder $3\frac{1}{2}$ in. diameter, this dimension being set by the radius at which the read and damping disks are disposed. With this arrangement the spiral responds only very slowly to changes in room temperature and zero movements due to this cause (and creep) are negligibly small (<0.01 mg) for most purposes over periods of a few minutes but readings can be interpolated if necessary.

Ni-Span C, from which the present spiral is made, is ferromagnetic but at the working distance of about 80 cm from the electromagnet the spurious weight changes (~ 1 mg) show no detectable hysteresis and are accounted for in the blank run.

The only drawback found with this simple balance arrangement is that it is not possible to distinguish between a torque and a straight pull on the specimen since both are seen as a rotation of the bottom of the spiral. With small, 4 mm long mm diameter, palladium specimens lying some $\pm 5^\circ$ around the vertical axis, the torque error, due to shape anisotropy, is about 2% and was corrected for by rotating the specimen to determine the mean value.

5. A suggested modification

This failing of the simple balance might perhaps be overcome by using an arrangement of two opposite-handed spirals hanging one below the other. If the bottom of the lower spiral is constrained by two fine quartz fibres to rise and fall without rotation, then the deflection output due to changes in vertical

specimen force can be taken from a mirror attached to the junction of the two spirals. As the quartz fibres do not have to extend or load the spirals in any way, except to resist the minute rotational forces, they can be quite flexible and should not appreciably lower the sensitivity of the balance which is very stiff in the vertical direction (2 mm extension per gramme). The inertial loading would still have to be attached rigidly to the mirror to retain the essential filtering action.

6. Conclusion

The original balance has been successfully used in magnetic susceptibility measurements at temperatures from 293°K down to 1.3°K . In this work the heavy load-carrying capacity of the device is useful in two respects. Firstly, it allows heavy (15 g) Gouy specimens to be measured when necessary. Secondly, with small Faraday specimens it eliminates the need for flat spirals to locate the specimen in the presence of unwanted sideways forces. In this case, the 15 g of ballast (pure lead) is disposed about halfway down the 50 cm long stiff quartz rod connecting the specimen container to the spiral; the resulting pendulum action effectively holds the specimen position constant.

Finally, it is suggested that this adapted gravity meter has wider applications as a weighing device than the present specialized use. The simple balance is a sensitive yet robust and inexpensive device which can support 40 g or more load, at least half of which is disposable, and yet it has a noise level of less than $2\text{ }\mu\text{g}$ under normal laboratory conditions.

Acknowledgments

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Simple form of balance for the rapid measurement of magnetic susceptibilities

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Abstract

A simple form of magnetic susceptibility balance is described which is capable of giving absolute determinations of susceptibilities of moderate magnitude, with a fair degree of accuracy. It is quite rapid in performance and has the added advantage that it can be used to investigate phenomena where transient changes in overall susceptibility are taking place.

1. Introduction

THE balance was developed in connection with an investigation where susceptibilities of a number of diamagnetic and weakly paramagnetic substances had to be measured. In addition the measurement of changes in susceptibility, occurring with change of physical and chemical conditions, was required. In its final form the instrument was so satisfactory from the point of view of accuracy, simplicity and rapidity of performance that it was thought that it might be worth while to describe it for others interested in work of similar nature.

2. General description of apparatus

In principle the balance uses a taut horizontal torsion wire in the same way as the familiar surface tension balance but several major changes are required to enable the principle to be used for the purpose discussed above. First a mirror and optical system are necessary to enable the minute displacements of the specimen to be detected and secondly the oscillation inherent in the system must be damped. Thirdly, a scale pan arrangement is needed if the magnetic force is to be compensated for directly by balance weights, in order that absolute measurements may be made.

A galvanometer mirror was mounted over the wire as shown in Fig. 1 (using a touch of shellac), a clear image of the fiduciary mark of the galvanometer lamp being obtained on a vertical scale some 1.5 metres from the balance. A steel wire of $\frac{1}{2}$ mm diameter was used initially but the possibility of a lighter weight system mounted on a more sensitive fibre (quartz, see § 3) arises, in which case satisfactory light weight mirrors can be made by silvering the thin circular microscope cover slips and protecting the back by a thin film of Perspex. This can be easily applied by dissolving the Perspex in chloroform and painting the back of the slide with the solution using a spray or fine brush.

A double mica vane system (Fig. 1) gave adequate air damping. Experiments still in progress suggest that this may be improved by surrounding the vanes by a Pyrex glass cylinder some $\frac{1}{4}$ in. larger in overall diameter than the vane. The lower vane is again mounted by a touch of shellac but the upper one is in contact with the under surface of the thin phosphor-bronze scale pan.

The main frame and stand of the instrument are in brass except the arm which is of duralumin and, as can be seen in Fig. 1, carries a scale and rider. This allows critical adjustment to be made for putting the specimen in the position of known field gradient necessary for the Faraday method.

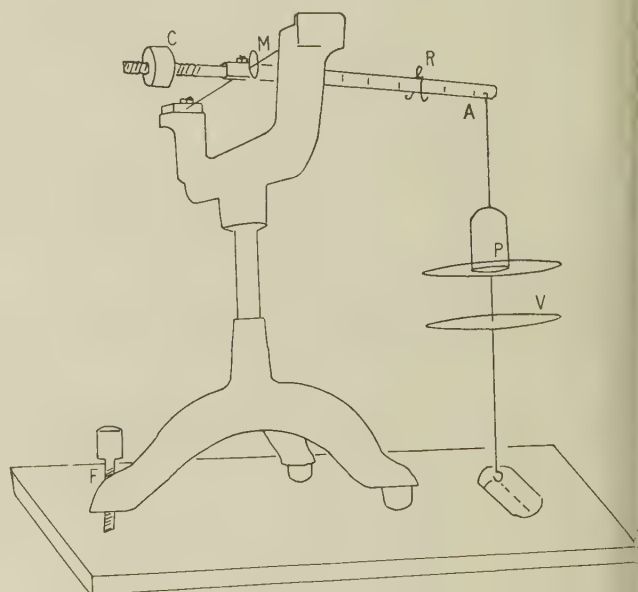


Fig. 1. M, galvanometer mirror mounted with shellac; V, double mica vane damping system; P, phosphor-bronze scale pan; A, duralumin arm carrying scale and rider R; C, counterpoise; F, screw foot.

this method is to be used it is desirable also to put a touch of shellac at any hooks or joints in the suspension (with the exception of that at the arm) to make them rigid, since displacement in one direction only is of interest and we wish to limit movement in any other direction.

The counterpoise C enables specimens of widely varying size to be accommodated whilst the screw foot F enables approximate adjustment of the HdH/dy position to be made before using the rider.

3. Calibration and performance

It was convenient at the outset to load the scale pan in order to confirm that a linear relationship exists between displacement and the applied force. The accuracy of the instrument depends upon this and the resulting graph (Fig. 2) showed that this was so to within 1%, an accuracy adequate for the purposes of the apparatus.

The scale upon which the image was obtained could be read to 0.05 cm (i.e. half a small division) which corresponded to a change in mass of about 3 mg. This was sufficient for many purposes where fairly strong paramagnetism was present and rapid reading was required, but for greater accuracy the specimen was restored to its original position,

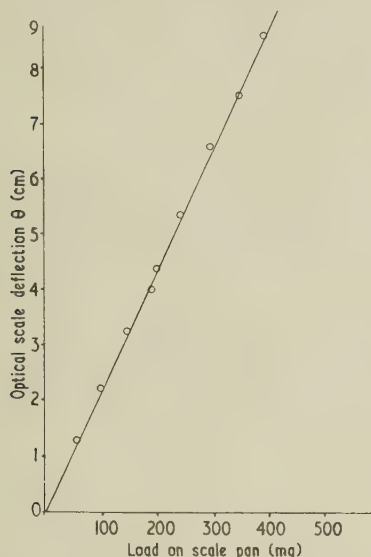


Fig. 2. Calibration curve for torsion balance.

the final adjustment being made using the rider. It was then necessary to calibrate the rider. The limit of accuracy here was imposed by the effectiveness of the damping system. Experiments using quartz fibres are still in progress and while, for example, a 0.4 mm quartz fibre gives a deflection of 5 mm against 2 mm when using the steel wire of 0.5 mm diameter and the same specimen, their use is restricted by the fact that they tend to sag and/or snap (a) if the specimen

is heavy (this involves making a compromise since reducing the size of the specimen reduces the magnetic force upon it), and (b) if the displacement is large. Thus diamagnetics and weak paramagnetics are the most suitable specimens here and substances of high susceptibility should be avoided. For general purposes there is no doubt that a 'non-magnetic' stainless-steel wire is to be preferred.

Three standards were chosen according to the order of magnitude of the specimens to be measured in each case. Water was used as the standard for low susceptibilities, molar nickel chloride for medium susceptibilities and ammonium ferrous sulphate for high susceptibilities. Table 2 shows the results of repeated experiments on each of these substances.

The torsion balance has the advantage that it can be used over a wide range of susceptibilities from diamagnetic substances of the order of -0.6×10^{-6} e.m.u. g^{-1} to paramagnetics of 30×10^{-6} e.m.u. g^{-1} without the necessity of changing the wire.

Using the Sucksmith ring balance a different choice of ring is required for different ranges of susceptibility.

A further advantage is that once the calibration has been made over the required range the deflection can be read directly and almost instantly, unlike the straightforward Gouy method which requires the specimen to be balanced for each measurement.

4. Results

Results using the Gouy method necessitated making allowance for the empty tube, when the Gouy expression becomes

$$(F - f) = \frac{1}{2}(k - k_0)AH^2$$

where F = total force on tube and sample, f = force on empty tube, k = susceptibility of specimen, k_0 = susceptibility of air displaced by specimen = 0.03 c.g.s. units.

From the calibration graph we see that the displacement

$$\theta = (\text{slope of graph}) m$$

Table 1

Substance	Susceptibility ($\times 10^{-6}$) (e.m.u. g^{-1})			
	1	2	3	4
Anhydrous manganous chloride	+108	107 $\pm$ 1	107	
Ammonium ferrous sulphate	+32.9	32.8 $\pm$ 0.2	32.3 $\pm$ 0.3	
Molar nickel chloride solution	+ 3.29	3.3 $\pm$ 0.1	3.3 $\pm$ 0.03	3.2
			by calculation*	
Aluminium	- 0.65	-0.63 $\pm$ 0.02	-0.65	
Pyrex glass	- 0.46	-0.48 $\pm$ 0.02		
Water	- 0.69	-0.75 $\pm$ 0.02	-0.72	

* The formula used for the purposes of calculation is

$$10^6\chi = \left(\frac{10030}{T}\right)\left(\frac{y}{100}\right) - 0.72\left(1 - \frac{y}{100}\right)$$

where y = weight per cent of nickel chloride in solution and χ = specific susceptibility = $k/\text{density}$. It is estimated to give an accuracy to 0.5% (Nettleton and Sugden 1939).

Table 2

Substance	Repeated results					
	32.9	32.8	32.8	32.6	32.7	32.6
Ammonium ferrous sulphate	32.9	32.8	32.8	32.6	32.7	32.6
Molar nickel chloride solution	3.3	3.3	3.4	3.4	3.3	3.2
Water	-0.75	-0.76	-0.73	-0.73	-0.77	-0.75

(where m is mass applied to pan) hence initial expression becomes

$$k - k_0 = \frac{2(\theta_s - \theta_t)g}{(\text{slope}) AH^2}$$

or

$$k = \frac{2g}{(\text{slope}) AH^2}(\theta_s - \theta_t) + k_0$$

where θ_s = displacement of tube filled with sample, θ_t = displacement of empty tube.

Pyrex glass, distilled water, nickel chloride solution, ferrous ammonium sulphate and aluminium were used to test the instrument for accuracy in operation. The results using the straightforward Gouy method, with a chemical balance, are given in the first column of Table 1. The second column gives the experimental results using the torsion balance, whilst the third column shows the results given by other experimenters.

5. Conclusions

The simple form of balance appears to enable transient changes in overall susceptibility, during (for example)

chemical reaction, to be followed quite easily and it appears could be easily adapted to work involving change in temperature. It also offers a method of checking HdH/dy values. For low susceptibilities of the order of 1×10^{-6} e.m.u. g^{-1} it allows accuracy to $\pm 2\%$, whilst with higher susceptibilities accuracy to $\pm 1\%$ can be obtained.

The instrument as used in the Faraday method compares favourably with the Sucksmith (1929) ring balance. The result using this method for molar nickel chloride solution and taking distilled water as the standard is shown in column 4 of Table 1.

Acknowledgments

Thanks are due to Mr. W. Pettifer for construction of apparatus associated with these studies. I am grateful to Dr. J. S. Wignall for his support and encouragement of this work.

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Metal cell for use in vapour pressure measurements by the effusion method

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Abstract

Full constructional details are given for an effusion cell made of Armco iron, which in conjunction with a calibrated vacuum spring and cathetometer has been used to measure vapour pressure over solid ferric chloride in the temperature range 100–200°C. The chief advantage claimed for the cell is that the effusion orifices, in interchangeable push fit end-caps, are of the form of true circular knife edged holes with easily determined dimensions.

Introduction

VAPOUR pressures in the range 10^{-4} to 10^{-1} mm Hg may be obtained by the Knudsen effusion method, in which the rate at which the substance evaporates *vacuo* through an orifice of small size is determined. One of the most convenient ways of determining this rate is by measurement of the contraction of a suitably sensitive spring from which an effusion cell is suspended, and such a technique has been described by Ubbelohde (1938).

If the rate of loss of weight of the substance in the effusion cell is to be correctly expressed in terms of the saturated vapour pressure, the effect of the presence of the orifice, and its departure from the ideal orifice postulated in the derivation of this expression must be considered. These problems have received much attention (Speiser and Johnstone 1950, Whitman 1952, 1953, Rossman and Yarwood 1953, Lyubimov and Polyanski 1959) and it emerges that to obtain vapour pressure data of significance, measurements should be made with cells of varying orifice area to vaporization area ratio, and a Clausing factor should be used to correct for the effect of the orifice tubulation.

We have found that the greatest obstacle to the exploitation of the effusion method is the provision of a range of cells, using the customary refractory materials (glass, silica, alumina, graphite), having orifices suitable for satisfactory area and orifice length measurement. This stems from the difficulties, without special techniques, in drilling and machining these materials, which difficulties largely disappear with the use of a metal. For the determination of the vapour pressure over solid ferric chloride in the temperature range 100–200°C, Armco iron was selected as material for the effusion cell.

Fabrication of the cell

A cylindrical cell was made and provided with interchangeable push fit end-caps each carrying an orifice of different diameter in the form of a knife edged circular hole. The dimensional details are given in Fig. 1. A plug carrying a small hole was riveted into the cell body and served to

attach the cell to its suspension. The shape of this plug, its dimensions and the method of riveting are shown in Fig. 2.

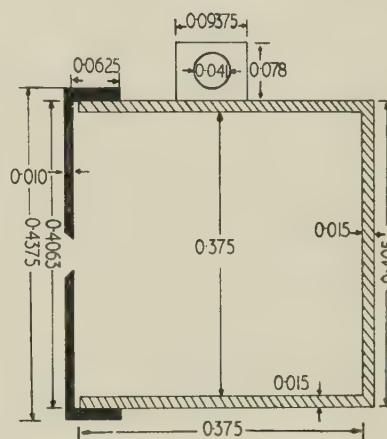


Fig. 1. The effusion cell. Dimensions in inches.

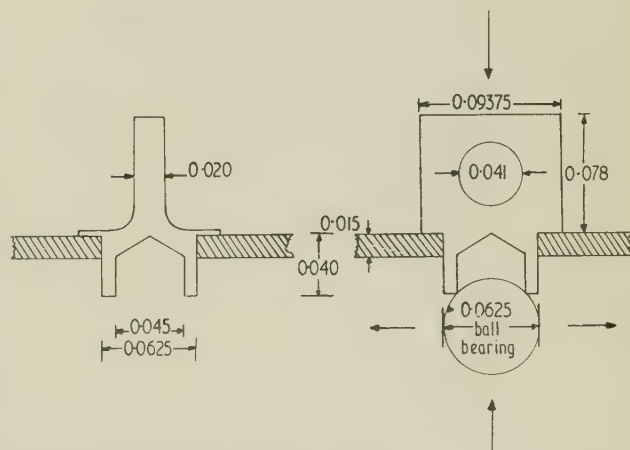


Fig. 2. Riveting the cell suspension. Dimensions in inches.

Measurement of the orifice areas and lengths

Ten diameters of each orifice were measured under a microscope using a Kellner micrometer eyepiece calibrated against a stage micrometer, and areas in the range 10^{-3} to 10^{-2} cm² were calculated with an accuracy to $\pm 3 \times 10^{-8}$ cm². At the conclusion of the effusion measurements, the end-caps were mounted, sectioned and polished as for metallographic examination and the orifice lengths were measured under the

microscope. Fig. 3 shows a cross section through an orifice. From these measurements a Clausing factor was calculated for each orifice using the procedure of Speiser and Johnstone (1950).

and allows a reasonable balance to be struck between the load carrying capacity and sensitivity of the spring on the one hand and the time to be allowed for effusion on the other. In addition the ease of manufacture gives rise to a secure

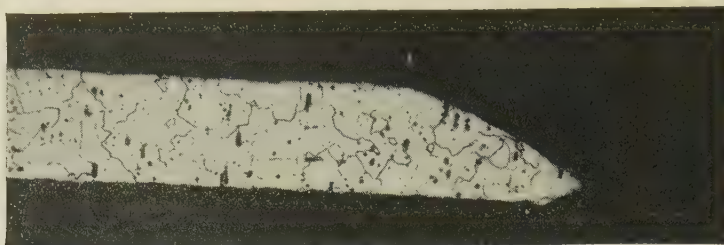


Fig. 3. A cross section through one side of an orifice illustrating the knife edging ($\times 55$).

Operation

The cell which weighed about 1.6 g and could contain up to 0.5 g of ferric chloride was easily filled by manipulation in a glove box. It was suspended by means of a thin tantalum wire from a calibrated glass spring (Still and Cameron) of sensitivity 9.857 cm g^{-1} in a continuously evacuated envelope, and heated by an oil bath. The contraction of the spring was measured with a cathetometer which could be read to 0.001 cm, over a total contraction of about 0.2 cm at each constant temperature. Three fillings of the cell for each end-cap used were required to cover the temperature range. After a run the cell end-caps could not be removed by hand but required gentle lifting with a tool consisting of a piece of thin flat spring steel containing a semi-circular hole at its end of diameter just greater than that of the cell.

Discussion

The main advantage of the metal effusion cell lies in the relative ease of producing orifices which closely approach the Knudsen ideal and whose dimensions are easily measured. The ability to fabricate the cell as a thin-walled cylinder is a further advantage in that it enables the cell to be as light as possible, consistent with suitable dimensional proportions,

and elegant means of suspension which greatly assists the technique of experiment.

In addition to Armco iron we have made similar cells in stainless steel and in copper, and there would appear to be little difficulty in the use of nickel, nickel-chromium alloys, titanium and zirconium. Such a range of materials would allow the use of the cell at high temperatures and judicious selection might avoid any problems posed by chemical interactions between the substance being studied and the material of the cell.

Apart from its use in the provision of vapour pressure data, such a metal cell may find use in further experimental studies of the effusion method itself and of accommodation coefficients in vaporization processes.

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Improved field discriminator for magnetic field stabilization

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Abstract

The automatic frequency control of a nuclear magnetic resonance field discriminator oscillator, using an external crystal reference and a germanium diode as a high Q voltage-dependent capacitor, is described. A frequency stability of 1 part in 10^7 is achieved, while allowing the frequency to be scanned through a range of 30 kc/s about the centre frequency of 30 Mc/s. The discriminator unit provides fine control of the 7000 G field of a large electromagnet and produces a corresponding 0.1% field scan with a stability better than 1 part in 10^6 .

1. Introduction

THE stability requirements of the magnetic fields employed in nuclear magnetic resonance spectroscopy are very stringent, and may not be easily attained in electromagnets of high current excitation. Even with the excitation current stabilized to 1 part in 10^6 , say, slow drifts in the value of the magnetic field may still occur because of temperature changes affecting the magnet geometry and permeability.

Nuclear magnetic resonance field discriminators, which may be used to stabilize the field directly, have been described in the literature (Packard 1948, Thomas 1952). The field discriminator normally consists of a simple form of an oscillating detector of the proton absorption signal in a water sample, from which is ultimately derived an error signal proportional to $H - (2\pi f_d/\gamma)$, where H is the actual value of the magnetic field, f_d is the frequency of the oscillator and γ is the gyromagnetic ratio for the sample nuclei. The error signal is fed back degeneratively to either the current generator or to auxiliary coils on the magnet, so as to maintain $H - (2\pi f_d/\gamma)$ as close as possible to zero.

The ultimate stability of the magnetic field thus depends on the stability of the frequency f_d of the discriminator oscillator. Crystal-controlled oscillators of conventional design may be used in this connection, in which case the magnetic field as a whole is not variable and the scanning of spectrum requires the use of a local bias field around the spectrometer head, with the consequent possible introduction of inhomogeneity into the magnetic field. Automatic frequency control techniques have been applied to stabilize the frequency of Pound-Knight-Watkins type marginal oscillators (Nolle and Henneke 1957, Mays *et al.* 1958, Blume 1958, Jenner 1961), which may be used as magnetic field discriminators. However, specific details of performance with regard to both frequency stability and frequency scanning have not been given.

In this laboratory a 30 Mc/s transitron negative resistance oscillator, based on the circuit of Knoebel and Hahn (1951), has been modified to allow the frequency to be scanned

through a range of 30 kc/s, while at the same time maintaining a frequency stability of 1 part in 10^7 . When used as a field discriminator to provide fine control through auxiliary windings on the magnet yoke, a corresponding magnetic field scan of 7 G is obtained in the 7000 G field of an 18 kw electromagnet (Bowen 1957). The main excitation current of 20 A is derived from a transistorized current-regulated supply.

2. Basic principle

The control of the oscillator frequency is accomplished by means of a voltage-dependent capacitor, which is incorporated in the tuned circuit of the oscillator. A signal at oscillator frequency f_d is mixed with the output of a master crystal oscillator f_c , and the resultant beat frequency f_b is fed into a frequency discriminator of centre frequency f_0 . The frequency discriminator develops a voltage v , proportional to $f_b - f_0$, which is applied to the voltage-dependent capacitor so as to oppose any change in oscillator frequency.

A block diagram of the feedback loop is shown in Fig. 1.

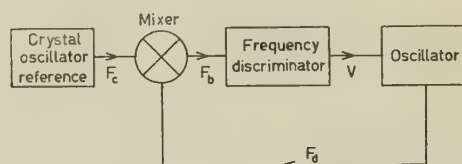


Fig. 1. Basic feedback loop for frequency stabilization.

Assuming linear relationships to hold for incremental operation over the ranges involved, the following equations apply:

$$f_b = f_c - f_d \quad (1)$$

$$v = \beta(f_b - f_0) \quad (2)$$

$$f_d = (f_d)_0 + \alpha v \quad (3)$$

where $(f_d)_0$ is the oscillator frequency in the absence of feedback, and α and β are constants determined by the design of the oscillator and frequency discriminator respectively.

On simplification, the equation for the feedback loop becomes:

$$f_d = \{(f_d)_0/\alpha\beta\} + f_c - f_0 \quad (4)$$

where it has been assumed that the loop gain $\alpha\beta \gg 1$, a condition which is easily realized in practice, values in excess of 200 being readily obtained.

Regarding f_c and f_0 as constant, Eqn (4) indicates that fluctuations in the oscillator frequency are reduced by the factor $\alpha\beta$ when feedback is applied, i.e. the stability is

increased by this factor. In considering the effects of f_c and f_0 on the overall stability, it will be assumed that variations of the crystal oscillator frequency are negligible. Since $f_d \approx 100 f_0$, the effect of f_0 on the overall stability will be less than 1 part in 10^7 , if f_0 is stable to better than 1 part in 10^5 . This latter figure may be achieved by careful design of the frequency discriminator.

Inspection of Eqn (4) also indicates that by the simple expediency of varying the tuning of the frequency discriminator within its range, a corresponding variation in the oscillator frequency may be obtained.

Since the object is to stabilize the oscillator frequency against slow drifts, it has been considered permissible in the above analysis to ignore the small but finite response times of the various elements in the feedback system. However, the phase shifts associated with the finite response times may cause the feedback loop to be unstable, and the insertion of an appropriate low-pass filter may be necessary to prevent hunting.

3. Design details

A schematic diagram giving certain details of the apparatus is shown in Fig. 2.

The crystal oscillator employs a Butler circuit (Buchanan

of the slope in the neighbourhood of the centre frequency which is the normal operating point of the discriminator when used in the feedback loop.

Since the ultimate stability of the oscillator is dependent on that of the centre frequency, the effects of temperature changes on the resonant frequencies of the two tuned circuits must be kept to a minimum. To this end, the temperature coefficient of frequency of the discriminator was made as small as possible by the inclusion of temperature-dependent ceramic capacitors, the appropriate temperature coefficient of capacitance being determined experimentally. As an added precaution, the discriminator was housed in a box separate from other items of electronic equipment.

The voltage-dependent capacitor

The voltage-dependent capacitor shunting the tuned circuit of the transitron oscillator must have a high Q value, and for this purpose it has proved convenient to make use of the voltage-dependent capacitance property of the depletion layer in a negatively biased germanium junction diode. Although considerable differences in characteristics exist between diodes of various types and between individual diodes of the same type, the Mullard type OA10 diode has been

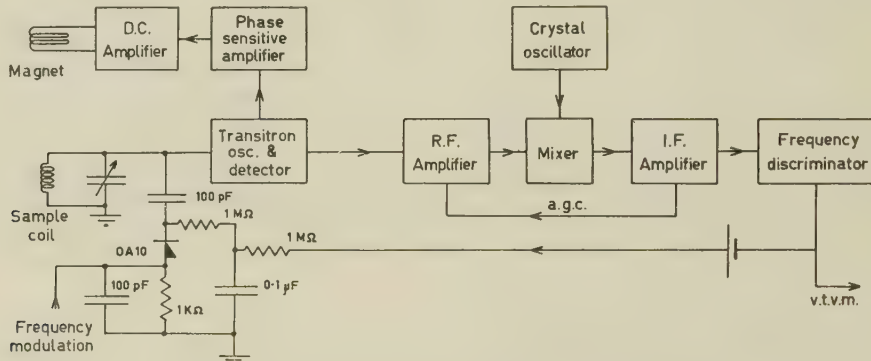


Fig. 2. Schematic diagram of the magnetic field stabilizer.

1956) with the 30–300 Mc/s crystal contained in an airtight hermetically controlled oven. The output of this oscillator is mixed with a 30 Mc/s signal derived from the detector of the transitron oscillator, and the resultant beat frequency signal at 300 kc/s (nominal) is amplified before being fed to the frequency discriminator.

Two stages of r.f. amplification before mixing are required: (i) to provide the necessary gain; (ii) to act as a buffer to prevent the transitron oscillator from pulling in to the crystal oscillator frequency; and (iii) to allow the provision of automatic gain control which, being derived from the output of the 300 kc/s tuned amplifier, assists in increasing the bandwidth of this stage.

The frequency discriminator

The two halves of the Foster–Seeley frequency discriminator, which are loosely coupled to the tuned output of the 300 kc/s amplifier, are themselves tuned 5 kc/s apart, and the motor-driven ganged tuning capacitor allows the centre frequency f_0 to be slowly varied through a range of 30 kc/s. The slope (β , Eqn (2)) of the output curve depends not only on the selectivity of the two tuned circuits and the spacing of their resonant frequencies, but also upon the magnitude of the induced voltages. With sufficient gain preceding the discriminator it is not difficult to obtain 10 volts per kc/s for the value

found to possess favourable Q and capacitance–voltage properties. Out of a batch of thirty OA10 diodes tested, six were found to possess characteristics similar to those shown

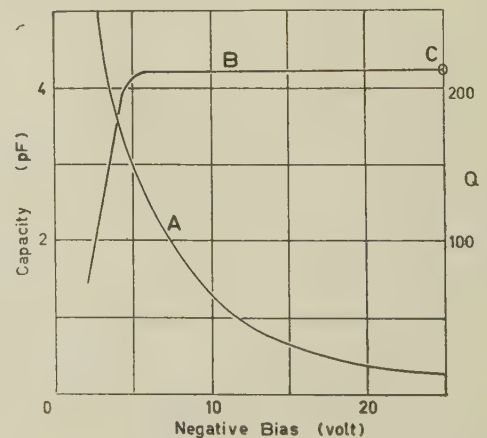


Fig. 3. Q and capacitance–voltage characteristics of a selected germanium diode.

Curve A, capacitance; curve B, Q of tuned circuit shunted by diode; point C, Q of tuned circuit alone.

Fig. 3, the remainder being rejected mainly on account of poor Q values.

It will be seen that at a convenient working point bias of 9 v, the slope of the capacitance-voltage curve has a magnitude of 0.15 pF/v, so that with the diode incorporated in the tank circuit of an oscillator operating at 30 Mc/s with total tuning capacitance of (say) 75 pF, a value of 30 kc/s per volt may be obtained for α (Eqn 3). The feedback loop gain would be 300.

In addition to providing a correction for slow drifts of the oscillator frequency, the voltage-dependent capacitance diode is also used to provide frequency modulation of the oscillator r.f. (in lieu of magnetic field modulation), which is required for its function as a nuclear magnetic resonance field discriminator. The method of applying both the d.c. bias and the a.c. modulation to the diode is shown in Fig. 2, together with the low-pass filter which is required to inhibit self-oscillation of the feedback loop and to prevent degeneration of the frequency modulation.

Performance

After an initial warming-up period, the recorded output of the frequency discriminator showed variations of less than 0.02 v, corresponding to frequency changes of less than 1 c/s, during a test run of one hour.

As a test of the stability and scanning of the magnet field itself, a nuclear magnetic resonance spectrometer was used to obtain the known line shape of the spectrum of ethyl alcohol. The motor-driven tuning of the frequency discriminator

produced a magnetic field scanning rate of 2.5×10^{-2} G/min, and from the reproducibility of results obtained for a number of alcohol spectra, the stability of the magnetic field was estimated to be better than 1 part in 10^6 . A factor limiting the determination of this figure was the field inhomogeneity over the sample volume, which was of the same order.

Acknowledgments

I wish to express my appreciation to Mr. E. Laisk of the Electronic Workshop of this School, who performed the initial investigations into the voltage-capacitance characteristics of germanium diodes.

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Self-contained integrating irradiance meter for use underwater

by L. DRAPER, M.Sc., A.Inst.P., National Institute of Oceanography, Wormley, Godalming, Surrey

MS. received 28th June 1961

Abstract

A self-contained instrument is described which will record the total light energy, within known spectral limits, received at a point during a period of time such as one day. It has a linear response to light intensity and makes its recording in digital form. It was designed to be used at sea. The integrator is basically electronic, not mechanical, so that it is not affected by the accelerations to which bodies floating near the surface of the sea are subjected.

1. Introduction

IN the study of the photosynthetic rate of phyto-plankton a knowledge of the quantity of radiant light energy available for photosynthesis is an important factor. Few direct measurements of the subsurface radiation have been made and most of these have been instantaneous measurements at one time of day (Currie and Draper 1961). This instrument was designed to measure the total amount of light falling at a fixed point in the sea over a period of time, usually one day. Its response is linear over a light intensity range of 1 : 500 (Stannard 1959). The integration is non-mechanical and is therefore unaffected by the moderate accelerations felt by a body just below the sea-surface. The output is a number proportional to the amount of light received and is displayed on a standard G.P.O. counter; this is an electromechanical device, but it is sufficiently robust to withstand the accelerations without making spurious counts. The instrument contains its own power supplies and needs no electrical connection to a buoy or ship.

Some previous integrating photometers are listed in the references (Bennett 1928, Blackman *et al.* 1953, Middleton 1953, Trickett and Mouldsley 1956).

2. Principle of operation and description of the electronic circuit

The output of a photo-emissive cell is stored in a capacitor. This capacitor is connected between h.t. negative and the trigger electrode of a stable firing cold-cathode trigger tube. When the voltage on the capacitor reaches the triggering voltage the trigger tube fires, causing a more powerful cold cathode tube to operate a G.P.O. counter which records one count, and, by means of contacts built into it, discharges the capacitor.

The most important problem in this instrument is that of retaining the charge on the capacitor when the instrument is recording light of low intensity. All possible electrical leaks into and out of the capacitor have to be eliminated or reduced until they become unimportant. For this reason it is not possible to connect the storage capacitor directly to the trigger tube, because the small leakage currents in the trigger electrode become comparable with the low-light current from the photocell when light intensity ranges greater than 100 : 1 are to be investigated. A hard valve inserted as a cathode

follower between the storage capacitor and the trigger tube overcomes this difficulty. As this valve is only required to operate when the storage capacitor voltage nears the trigger voltage, a low-voltage, low-consumption, deaf-aid valve is used with its cathode resistor connected to a voltage supply just below the triggering voltage of the tube. By this means the valve comes into operation shortly before the capacitor is fully charged, thereby using no power for most of the cycle. The connection between the storage capacitor and the discharge contact on the relay has to be extremely well insulated. One of the normal contacts on the counter is removed and the highly insulated line from the storage capacitor put in its place. When the counter operates, the original contact, which is connected to h.t. negative, moves up to touch the new contact and discharge the capacitor. (For circuit diagram see Fig. 1.)

To maintain the insulation of the storage capacitor at the maximum level, the electronics are contained within a sealed, dessicated compartment and the power supplies are fed in through hermetic seals. If the unit is assembled in moist conditions the insulation will improve over a period of several weeks of dessication; a higher ambient temperature accelerates this drying process. Leakages into or out of the capacitor can usefully be controlled by adjustment of the voltage level of the chassis of the instrument. In this way the very low intensity response can be improved.

It would be possible to operate the G.P.O. counter directly from the stable-firing trigger tube, but as the passage of large currents would tend to damage the tube and destroy its reliability, a second trigger tube, designed to transmit large amounts of power, is used to operate the counter. The amount of power used by the first trigger tube is thereby made very small.

In the instruments designed for use at sea in difficult conditions, mercury switches are built into the power supply connections, so that merely by placing the instrument in its operating attitude, i.e. photocell pointing upwards, the instrument is switched on. By inverting the instrument the power supplies are automatically conserved.

Temperature changes are unimportant. No change in the calibration of an instrument was detected during a change in temperature from 8 to 19° C.

3. Response of the instrument

Linearity of response is to within $\pm 2\%$ down to 1% of maximum recording rate and $\pm 5\%$ down to 0.2% of maximum recording rate.

For use in investigations of the total amount of light received over one day, a linear response over a range of 1 : 100 is almost certainly adequate. When the light intensity is less than 1% of the maximum, the total amount of light energy received at the earth's surface is only about 0.1% of the daily total; even when the intensity is less than 10% of maximum, the energy received is only about 1% of the daily total.

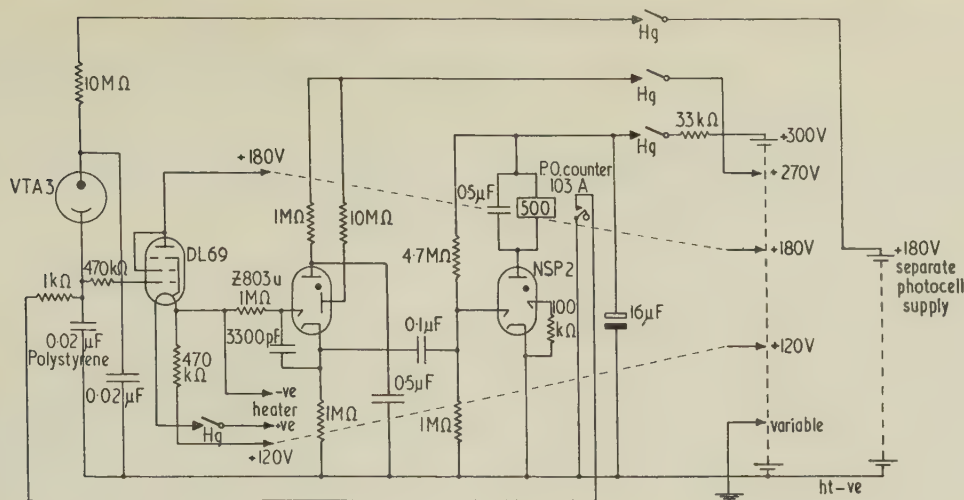


Fig. 1. Circuit diagram.

4. Battery supplies

Power is supplied by ten 30 v deaf-aid batteries and, for the heater of the cathode follower, by a mercury cell. To maintain a constant voltage on the photocell, separate batteries are used for this purpose only. The instrument will operate satisfactorily when the voltage of the main battery pack drops by over 10%. The photocell supply batteries can be used repeatedly and need not be replaced as frequently as the main batteries. A standard battery pack using 30 v batteries (type 123) contains enough power to produce 60 000 counts over a period of a few weeks, but it is probably advisable to discard the main batteries after about 10 000 counts. The mercury cell will run continuously for twenty days.

5. Mechanical construction

The electronic circuit is built into a partially cut-away brass tube (see Fig. 2). The photocell is at one end of the

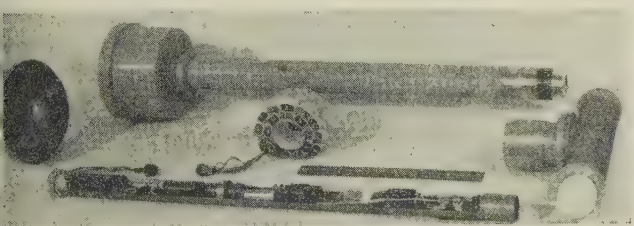


Fig. 2. Integrating irradiance meter and pressure casing, with omnidirectional head.

tube and the counter at the other. This brass tube is located precisely into a pressure casing consisting of an aluminium tube 2½ in. outside dia. × 1½ in. inside dia. × 30 in. long. The light-receptor head is screwed to the top of the aluminium tube and sealed with an O-ring. The battery box is a casting around the lower end of the aluminium tube. The battery box lid is also sealed with an O-ring. The electronic assembly is hermetically sealed within the aluminium tube so that the light receptor and batteries can be changed without allowing moisture to penetrate to the electronics. The counter is visible through a plate glass window in the battery box lid. The weight in air, complete with batteries, is 23 lb.

6. Optical arrangements

The instrument can be used with a flat-plate receptor or with an omnidirectional head (Currie 1961). The incident light is diffused by flashed-opal glass. For use in the sea a blue-green filter combination consisting of 1 mm thicknesses of Schott BG12 and GG5 glass is used below the opal. When used with a type A photocell cathode this gives a combined response of filters and photocell with a peak at 465 mμ. This is about the wavelength of maximum transmission into oceanic waters. A neutral density filter is incorporated in the light path except at the lowest intensity. The density of filter chosen for any particular instrument is dependent on the expected light intensity at the point of operation; these filters are easily interchanged.

7. Calibration

The instrument is held in a frame and exposed to a constant light source. The time interval between successive counts is measured with a stop-watch. Neutral density filters of known density are inserted in the light path and the time interval is measured again. In this way the linearity is checked.

8. The use of the instrument

When erecting the instrument care must be taken to do so in dim light or with a protective cap over the photocell. If the storage capacitor reaches triggering voltage before the trigger tube is able to fire, i.e. before its anode capacitor has time to charge (about 1 second), a discharge may be initiated between trigger electrode and cathode which does not extinguish itself. This type of discharge may damage the tube. Switching the power supplies off and on will fire the tube and the instrument will be ready for operation.

For use in photosynthesis work it is normally adequate to arrange for the instrument to record a total of 500 to 1000 counts during one day. The instrument is capable of recording at a much faster rate. In bright sunlight an instrument with a 1% neutral density filter will make a count every five seconds. This is the maximum permissible rate and is ten times the rate required for optimal daily count.

Counts at a faster rate than one every five seconds exceed the current rating for the photocell.

9. Conclusion

This instrument is designed to fulfil a specific need but it can obviously be used for light measurement in other applications. The primary requirement in this case is for a completely self-contained instrument which can be left suspended from a buoy at a point in the sea and which will record the total amount of light received at that point. It can be handled at sea in poor conditions and leaves the research ship free to do other work during the day instead of staying in the area. Although it is designed in this instance for biological work it could easily be used to measure light in many other applications. Without its stout pressure casing it could be made very light in weight and be used as a portable irradiance meter. If the instrument is used in an accessible place the average irradiance over short periods can be measured by timing the interval between successive counts.

Acknowledgments

The author would like to express his thanks to the Director and staff of the National Institute of Oceanography for help

and encouragement during the design and testing of the instrument and, in particular, to Mr. R. I. Currie, the biologist who first suggested the need for such an instrument and who has taken an active interest in it throughout its design and testing; also to Mr. E. J. Stannard of the Services Valve Test Laboratory who calibrated the prototype instrument. The facilities and help given by the Director and staff of the Marine Station at Millport for the sea trials were greatly appreciated.

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X-ray diffractometer for automatic operation

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Abstract

A description is given of an X-ray diffractometer, designed for automatic operation, using punched tape input information. Four circles are normally used. Two large 360-tooth circles, having their axes vertical and collinear, are used to set the detector and the plane of the vertical circle respectively. The third circle provides a rotation about a horizontal axis of the fourth circle, on which the goniometer head is mounted. The gear mechanism for ensuring the independence of the last two settings is described. The merits of a complete vertical circle as compared with quarter-, half- and three-quarter circles are discussed, and it is shown that the mechanical advantages of a complete circle generally outweigh the disadvantages due to obstruction of the X-ray beam, which are, anyway, much less than commonly supposed.

1. Introduction

THE need to make measurements of X-ray reflections from given lattice planes automatically is becoming increasingly urgent, and the instrument described here has been designed to this end. Assuming that the cell dimensions and axial angles are known, it is now straightforward and relatively quick to calculate, by means of an electronic digital computer, the corresponding setting angles for a single crystal on a diffractometer. To make use of the facilities of digital computation a mechanical arrangement is required which enables the crystal and detector to be set in any desired orientation with the requisite accuracy and speed.

2. Details of design

The present instrument utilizes complete worm wheels only as the basic elements for setting the crystal. Generally speaking four circles are all that are necessary. If required an arc can be fitted to raise the detector through 60° from the horizontal. Following the definitions given by Furnas (1957) these circles are known as ω -, 2θ -, χ -, ϕ - and ν -circles respectively. The ω - and 2θ -circles are about 23 cm in diameter and have 360 teeth. They rotate about a common vertical axis. In common with all the other driving worms of the instrument, these worms are provided with an anti-backlash mounting.

The lower (ω) worm wheel drives the shaft A, Fig. 2, on which is mounted the platform B. The vertical (χ) circle (Figs 1 and 2) attached to this platform is carried in two ball-races C, C' and driven by a worm D. On the shaft of C is mounted a spiral gear which is driven by a motor and gear-head through the shaft E. The ϕ -circle is mounted on axis X which intersects the axis of the χ -circle at the point where the main vertical axis of the instrument passes through it. The worm wheel of the ϕ -circle F has 360 teeth

and is driven by a worm G, provided with an anti-backlash mounting H. This anti-backlash device consists of a sphere turned on the shaft of the worm G and held between opposed cones. The driving mechanism of the ϕ -circle consists of a train of spur gear wheels I, J, K, L, the last of which engages

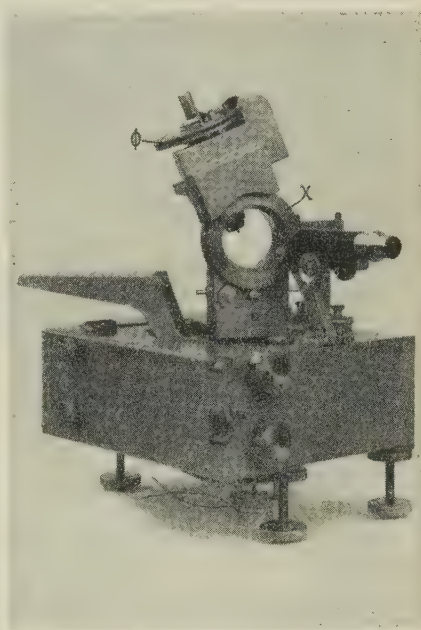


Fig. 1. Photograph of the diffractometer showing the χ - and ϕ -circles. (By courtesy of Crystal Structures Ltd., Cambridge.)

with the spur wheel W of a differential. The necessity for a differential arises from the fact that we require the ϕ -circle not to rotate as the χ -circle rotates. This is achieved in the following way. Two 240-tooth spur gear wheels, M, N, are mounted coaxial with the χ -circle. Wheel M is rigidly attached to the vertical non-rotating frame; N is capable of being driven round by a spur gear wheel P, which is in turn driven by a motor and gear-head. The operation of the differential can be understood in the following way. Suppose that the motor driving P is stationary. Now keep the axis of the ϕ -circle vertical but allow the frame of the χ -circle to rotate by driving the shaft E. (This is simply a convenient way of considering the relative motion of the gear wheels.) The wheel M drives spur wheel Q in, say, a clockwise direction while the wheel N drives the wheel R at the same speed, through an idler S, in an anti-clockwise direction. Wheels Q and R drive spur gears T and U respectively. Wheels T and U mesh with one another and are carried on a frame capable

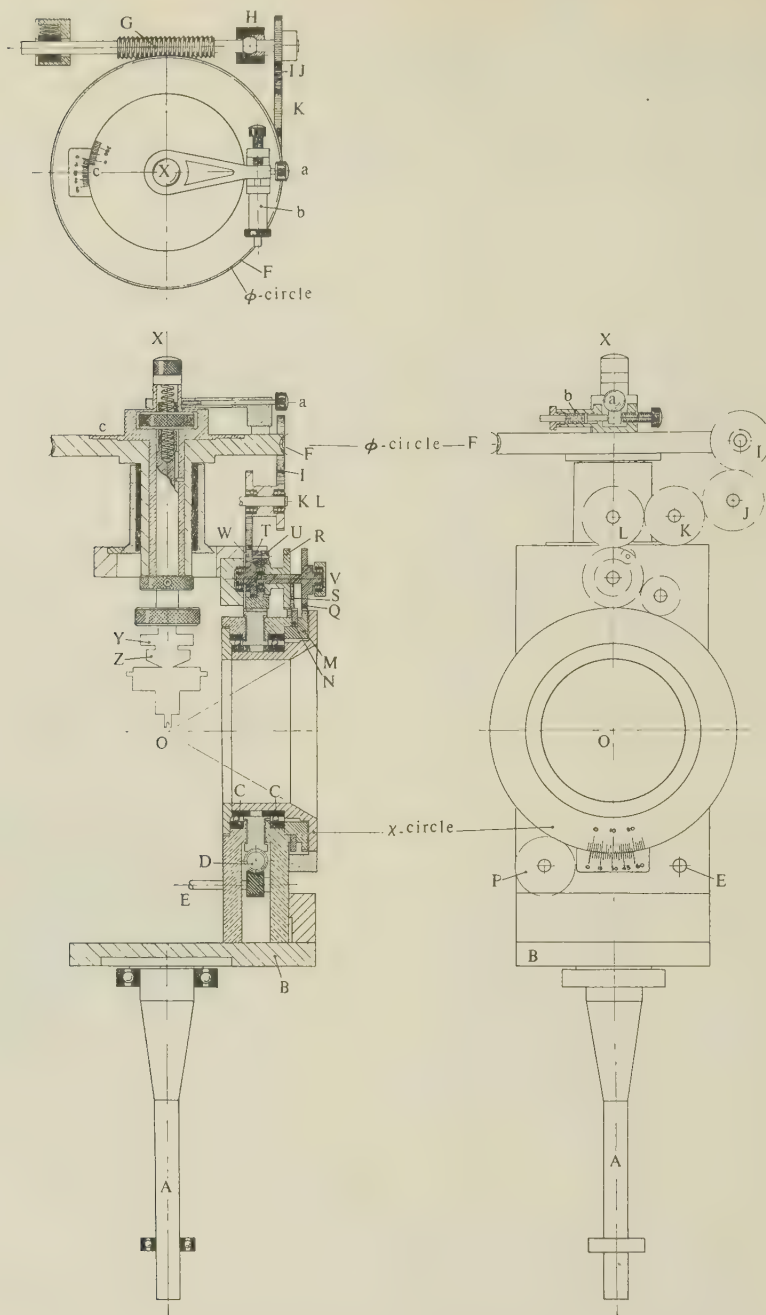


Fig. 2. Plan, elevation and side-view of the vertical circle.

of rotating about the axis V. A spur gear wheel W on this frame meshes with the wheel L. Since T and U are rotating at equal speeds in opposite directions the wheel W does not rotate and the ϕ -circle remains stationary. If however the 240-tooth wheel N is rotated relative to wheel M, then the wheels T, U do not rotate at equal speeds and the wheel W rotates accordingly. Thus rotation of the shaft E rotates the χ -circle without affecting the ϕ -circle, and rotation of the P-shaft rotates the ϕ -circle.

The axis of the ϕ -circle X is provided with an adjustment along its length so that, with the two transverse slides Y, Z on the goniometer head, three linear adjustments of the crystal are provided. To facilitate initial settings the goniometer head may be rotated relative to the worm wheel of the

ϕ -circle by unclamping the screw a. The setting can be adjusted using the tangent screw b and the divided scale c.

The shaft A may be rigidly attached to the ω -worm wheel or it may be oscillated with respect to it by a device due to Arndt, Faulkner and Phillips (1960). (This device can be seen in part at the bottom of Fig. 1.)

The ν -circle can be attached to the arm supporting the detector (scintillating crystal, or proportional counter) and rotates the arm in a vertical plane through an angle up to 60° .

3. Method of use

The cell size and angular elements are known or can be found in the usual way. This information is fed into a

digital computer which gives the angles 2θ , ω , χ and ϕ . There are two alternative settings of the vertical circle; in one the x-rays pass through the circle on the way to the crystal and then pass out on the other side, in the other arrangement either the incident nor the reflected x-rays pass through the vertical circle. When θ is small, for example less than 30° , ϕ can always be made equal to θ , since the semi-angle of the cone of rays which can pass from the crystal through the vertical circle is 30° .

When θ is greater than 30° , ω , χ and ϕ can be chosen by a programme fed into the digital computer so that the reflection can be recorded in the horizontal plane through the crystal. The dead space caused by using a complete χ -circle rather than a quarter-, half- and three-quarter circle is generally negligible. (This is shown in a paper to be published later.) A limitation exists along the axis of the ϕ -circle where ξ -values between 1.00 and 1.73 cannot be recorded. The remaining unexplorable region has the shape of a spinning top, having its axis coincident with that of the ϕ -circle and a volume less than 1% of the explorable volume of the used half of the limiting sphere. The advantages of recording only in a horizontal plane are: (i) that the polarization and Lorentz corrections are simply functions of θ , and (ii) that absorption corrections are easier to make. There is also a mechanical simplification if the detector arm does not need to be raised.

4. Accuracy and long-term reproducibility

It has been found very difficult to make part circles which remain truly circular over a considerable length of time. It is necessary to make them relatively heavy if they are to retain their accuracy. For this reason complete circles have been used throughout in this diffractometer. The dis-

advantage of the obstruction due to the supporting vertical circle is almost completely overcome with digital computers to take account of instructions for changing the angles when required. The worm wheels have been made sufficiently large so that an accuracy of $\pm 1'$ at any point round the circle can be achieved. The anti-backlash arrangement ensures that no backlash greater than $1'$ occurs. There is provision for taking up any wear of the sphere in cones of this mounting.

5. Driving motors and setting devices

Four motors are used, one for each of the 2θ -, ω -, χ - and ϕ -circles. These are split-phase motors running at 3000 rev/min approximately and working through gear heads, giving 50 and 100 rev/min output speeds. The setting device is based on five digits enabling the final setting to be made correct to 0.01° . The driving worm operates a counter based on a Geneva type gear motion and the digit wheels are set successively. The arrangement used here takes the information from standard five-hole punched tape and momentarily stores this information in a memory consisting of a bank of uniselectors, each one of which corresponds to one digit of the required five-figure number. When the setting of the given circle has been effected the whole process begins for the next circle. Thus the circles are set successively and the method depends not upon counting a number of pulses but upon a matching of digit circles in turn.

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Low-velocity gas-liquid impinger for the continuous estimation of sulphur dioxide and other atmospheric pollutants

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Abstract

The instrument records sulphur dioxide conductimetrically in the range 0.01 to 10 parts per million where rapid changes in concentration can be expected but the accuracy required is not more than 1 in 20. Sampling is continuous and cumulative, with a return to initial conditions two or three times an hour. The principle of operation is the removal of a soluble vapour from an air jet impinging on to an unbroken liquid surface. One modification of the instrument measures light absorption instead of conductivity, permitting the use of colorimetric reagents.

Introduction

THE concentration of atmospheric sulphur dioxide at a fixed station (St. Bartholomew's Hospital) sometimes varied abruptly because of the contribution from local sources. Routine daily or hourly samples failed to distinguish these peaks from the background pollution, and it was therefore decided to set up an automatic sampler and recorder, using the well-tried peroxide-conductivity method. The following considerations were felt to be relevant: (i) In estimating pollution from the health aspect, about 10% accuracy is sufficient. (ii) The general level of pollution from acid gases at any time should be immediately apparent so that periods of special interest can be picked out of a mass of records. (iii) As the detector solution would sometimes be working at the limit of sensitivity, there should be some way of allowing for drift. (iv) There should be a rapid response to changes in concentration. (v) Running time should be at least two days without attention. (vi) A small instrument with a low sampling rate is most easily adapted for field work.

Construction and operation

The design is based on the observation that a low-velocity jet of air containing sulphur dioxide can transfer it very efficiently to the surface of dilute hydrogen peroxide, and then by rapid micro-circulation to the underlying solution. Air is drawn into the cell compartment D (Fig. 1) through a filter F and a glass jet J, blowing vertically down on to 0.1-volume peroxide in the cell C in which sulphur dioxide is scrubbed from the air and converted to sulphuric acid. The electrical conductivity of the solution in the cell is measured through electrodes E connected to a simple oscillator, amplifier and recorder. Fresh solution runs by gravity from a reservoir through a fine plastic tube M to a siphon S. The latter is connected to the cell compartment by its delivery tube and also by a pressure-equalizing tube P; a manometer (not shown) is connected across the jet.

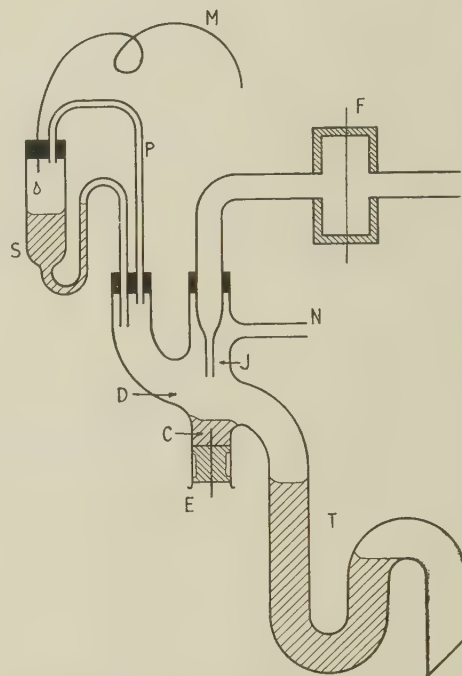


Fig. 1. Absorption cell and siphoning system. M, reservoir delivery tube, 4-6 ft of P.T.F.E., inside diameter 0.022 in.; S, siphon, about 5 ml.; D, cell compartment, 1 cm inside diameter, Pyrex; C, cell; J, jet, inside diameter 0.5 mm; E, electrodes (one behind the other), 18 s.w.g. stainless steel wire, 0.6 cm apart; F, air filter, Whatman GF/A; N, outlet to suction pump (small vibratory diaphragm type).

Periodically the siphon discharges and flushes out the cell, overflow going to waste through a trap T. Every time this happens the reading, which had risen steadily because of the increasing sulphuric acid concentration, returns sharply to 'zero'. The exact point of return is not important, since it is the slope of the saw-tooth record (Fig. 2) which defines the instantaneous concentration, and the difference between readings at two points on any one saw-tooth which defines the total amount of gas collected between the indicated times.

The vapour reaction

Francis *et al.* (1938) measured sulphur dioxide in washed flue gases by absorbing them into dilute hydrogen peroxide (exact strength not specified) and measuring the conductivity. They mention disagreement about the efficiency of collection, the probable reason for which became apparent only recently. Experiments were done in this laboratory to detect sulphuric

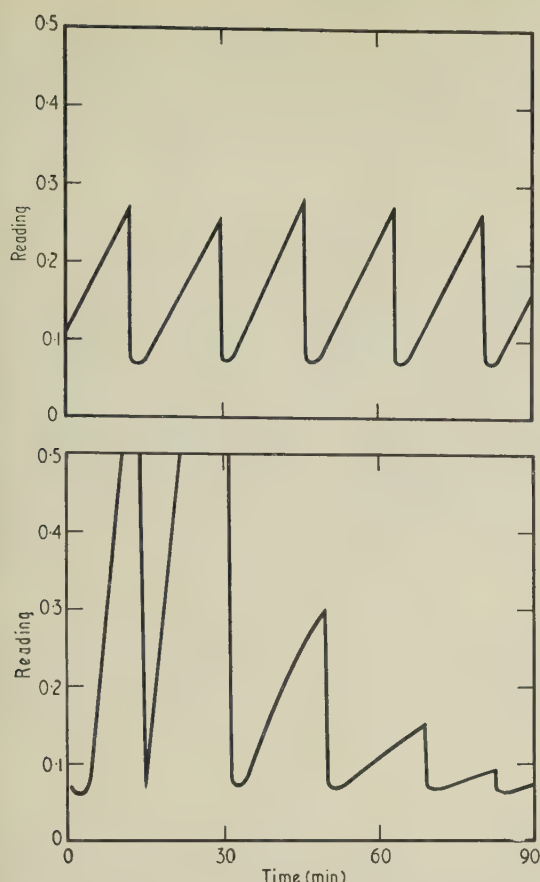


Fig. 2. Upper trace, record from air containing 0.10 to 0.14 part per million of sulphur dioxide. Lower trace, record from air in which 1.5 parts per million of sulphur dioxide was allowed to ventilate away to 0.01 part per million in about 90 minutes.

acid in the smoke from burnt fuel oil, and in order to remove unwanted sulphur dioxide the combustion gases were passed over 20-volume peroxide. It was then found that a mist of sulphuric acid was formed by a fast vapour reaction between hydrogen peroxide and sulphur dioxide. Pure peroxide at 5° C is in equilibrium with 1300 parts per million of vapour, so that appreciable quantities could be given off by its aqueous solution. The vapour reaction was not investigated in detail, but it was clear that any absorption system not including filtration or high-velocity impingement could be expected to lose sulphur dioxide as acid mist with concentrations greater than 10 parts per million brought into contact with peroxide stronger than about 1 volume. In urban air the sulphur dioxide concentration seldom rises above 1 part per million, so that this problem does not arise; 0.1-volume peroxide is, in any case, adequate (see below).

Electrical circuit

A double-triode Wien bridge oscillator working at about 6 kc/s operates a cathode-follower which supplies low-impedance a.c. to one side of the cell. The other side is connected to the grid of an a.f. pentode and shunted to earth by a low resistance, about 1 k Ω , whose exact value defines the sensitivity. The output from the pentode feeds another cathode-follower, whose output is rectified and passed to the recorder. By making the input and output impedances at the cell much lower than that of the cell itself,

it is possible to make the reading directly proportional to the conductivity of the solution.

Stock solution

The reservoir contains 5 μ M sulphuric acid and 0.1-volume peroxide in distilled water. The acid is put in to suppress the buffering action of bicarbonate ion from atmospheric carbon dioxide; 5 μ M is sufficient in practice (see calibration below) and also fits with a calculation of the carbonate-bicarbonate equilibrium in relation to pH. Increasing the concentration of peroxide made some improvement in the efficiency of collection, but this was already so high (see below) that no material advantage resulted, while there was the increased risk of oxygen bubbles, both in the cell and blocking the reservoir delivery tube. It should be noted here that the electrodes must not be platinum, because of the severe bubbling it causes by catalytic decomposition of the peroxide.

Jet characteristics

Experiments were done with pairs of similar jets in series, 1 cm from the surface of separate 10 ml. lots of stock solution, sampling at various rates from air containing about 1 part per million of sulphur dioxide. The efficiency of collection per stage was reckoned as $100(A - B)/A$ where A and B were the increases in conductivity in the first and second lots of solution respectively. Results were as follows, in percentages (* denotes rupture of the solution surface):

Jet diameter (mm)	0.1	Flow (l./min) 0.2	0.5	1.0
0.5	98	96	*	*
1.0	98	95	94	*
2.0	95	87	72	57

In further experiments with 0.5 mm jets at 0.2 l./min, it was found that the collection efficiency stayed between 95 and 96% on moving the jet from very close to the solution surface to a distance of 2 cm. A flow of 0.2 l./min is adequate for recording sulphur dioxide in town air if the liquid volume is small enough, as in the present instance. The 0.5 mm jet is only slightly more efficient than the 1 mm one, but was chosen because it set up a much stronger circulation in the solution, and also had a sufficient pressure drop across it to permit it to function as a manometric flowmeter. The jet specifications are thus as follows: diameter, 0.5 to 0.55 mm; pressure drop, 3 to 5 cm w.g.; distance from surface, about 1 cm; flow, 0.2 l./min; collection efficiency, 96%.

Time constant

The speed of response of the instrument depends primarily on the rate of mixing in the cell. The micro-circulation set up by the air jet can be observed by putting small particles into the solution, and extends only a few millimetres from the dimple. Tests were done on one cell, connected up in the normal manner and of the usual diameter, 1 cm, but whose depth could be varied. The flow was set to 0.2 l./min and a slug of air containing several hundred parts per million of sulphur dioxide was fed in a pre-determined time. The subsequent reading was followed, and the times taken to reach 90% of the final value were 5, 6 and 9 seconds for cell volumes of 0.7, 0.9 and 1.2 ml. respectively. Allowing one second for the slug to reach the jet, the time constants were 1.75, 2.2 and 3.5 respectively. An instrument with a 0.9 ml. cell should therefore respond well to fluctuations in

sulphur dioxide concentration due, for example, to changes in wind direction. A smaller cell would respond still faster, and be more sensitive, but certain errors then become noticeable (see below).

Calibration

If the cell is flushed out, first with stock solution and then with the same solution to which has been added a known concentration A of sulphuric acid, the reading will change by an amount depending on the strength of the acid. The same change in reading could have been obtained by shunting the cell with some resistor R . With a linear relation between reading and conductance RA is a constant, known as the *cell constant*. For the six cells so far made RA has been between 1 and 3 mole ohms. Knowing RA , it is possible to calibrate any amplifier/recorder system working from the cell, by using a single accurate resistor. The procedure is illustrated by considering the instrument now in use, whose cell constant RA (measured at 20°C) is 1.57 and retained volume is 0.9 ml. At a sampling rate of 0.2 l./min, the acid strength in the cell will increase by $89\ \mu\text{M}$ every ten minutes if the air contains 1 part per million of sulphur dioxide, reckoning 24 l./mole at 20°C and an efficiency of 96% . It was required to obtain full-scale deflection on a milliamp recorder for a ten minute sample from air containing 0.5 part per million of sulphur dioxide, corresponding to $44.5\ \mu\text{M}$ acid. A $47\ \text{k}\Omega$ resistor was available, whose 'acid equivalent' is given by $47000 A = 1.57$ or $A = 33.4\ \mu\text{M}$. The increase in reading caused by shunting the cell with the resistor had therefore to be adjusted to be $33.4/44.5$ of full scale, or 0.75 mA; this was done by means of a potentiometer on the cell output.

Determination of the cell constant is illustrated in Fig. 3; the upper plot shows the reading as a function of acid

strength, while the lower plot shows the reading as a function of $1/R$, where R is a resistor joined in place of the cell. Both plots are adequately represented by straight lines passing through or very near the origin, as long as the solution contains more than $5\ \mu\text{M}$ acid, as specified. The cell constant is the ratio of the slopes of the two lines.

Performance

Figure 2 shows tracings from two records, the first from an atmosphere with an approximately constant sulphur dioxide concentration, and the second from an atmosphere in which the concentration was changing fast and over a wide range. Rounding off of the lower corner of each saw-tooth is due to evaporative cooling of the solution in the cell by the air jet. This causes an initial rapid but small drop in conductivity, which soon merges with the much bigger steady rise due to gas absorption. Only in very low pollution are the two effects comparable, and even then the estimate of concentration, based on the slope, should still be reliable—one has merely to ignore the initial curved portion of each saw-tooth.

Sampling at higher gas concentrations

Tests with 0.5 mm jets in series, at 0.2 l./min, showed that the collection efficiency fell only slightly on increasing the sulphur dioxide concentration, to 95% at 10 parts per million and to 94% at 100 parts per million.

Errors

There does not seem to be any systematic error in the instrument, since good agreement was obtained with the standard method of sampling sulphur dioxide, in which high-volume samples are titrated against borax using 4.5 indicator. Some early underestimates, amounting to as much as 50% , were traced to the use of a rubber input tube. It is most important, with the relatively low sampling rate of the instrument, that nothing should be interposed before the jet which could absorb sulphur dioxide, or release soluble vapours (one plastic tube was found to give off an alkaline vapour). A clean metal tube, such as $\frac{1}{2}$ in. copper, should always be used.

A temperature increase of one centigrade degree causes an increase in electrical conductivity of dilute sulphuric acid of 1.55% , a decrease in air density of 0.35% and an increase in its viscosity of 0.3% . Estimates of sulphur dioxide concentration should therefore be increased by 0.9% for every centigrade degree below 20 , remembering that the cell temperature will be one or two degrees below ambient because of evaporation. Slow drifts in temperature will also affect the 'zero' but not the slope of the record, except as just indicated.

Minor errors arise from uncertainties in the retained volume of the cell, due to surface tension irregularities at the overflow, and also from loss of solution by evaporation. Tests showed that these two errors were comparable and not greater than 2% for the 0.9 ml. cell; with a smaller cell they would be more serious. Changes in flow of solution into the siphon, and contamination of the reservoir solution itself, would change the wavelength and 'zero' of the record respectively, but should not affect the slope.

Advantages

A sulphur dioxide recorder described by Cummings and Redfearn (1957) has a rather elaborate absorption cell

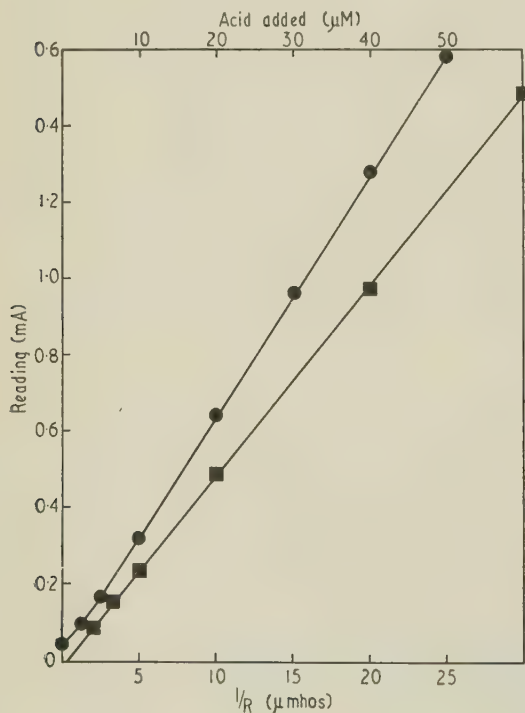


Fig. 3. Calibration of cell at 20°C using sulphuric acid (circles) and 1% resistors R connected in place of the cell (squares). The ratio of the slopes of the two lines defines the cell constant, 1.57 mole-ohms.

rate from the conductivity cell, the whole being thermally controlled. This kind of elaboration is found in commercial instruments now available. The advantage of the jet sampler is that gas absorption and measurement of conductivity are done in the same small cell, with consequent simplicity and speed of response.

Measurement of carbon dioxide

By using 0.1 mM alkali in the reservoir, and no peroxide, it is possible to record carbon dioxide concentration in the range normally encountered in air. A negative saw-tooth record is now obtained, since absorption of carbon dioxide changes hydroxyl ions into less mobile carbonate or bicarbonate ones. Experiments with jets in series showed a collection efficiency of only 2.5%, but the response still seemed quite fast and it was easy to follow the die-away by titration of a few litres of the gas released into a room. Anolamine solution was no more efficient than alkali.

Other modifications

A different version of the instrument was made in which the cell had no electrodes, but was simply rounded off. It

was then seated in a block drilled to hold a small light bulb and a Mullard ORP 60 photoconductive cell. The latter was connected directly to a recording milliammeter through a battery. Using a green filter and Saltzman's (1954) reagent, nitrogen dioxide could be continuously estimated at a collection efficiency of 35%.

The cell could in principle be fitted with pH electrodes, or a dropping mercury electrode, but no work was done on the feasibility of such arrangements.

Acknowledgments

I am indebted to Mr. B. T. Commins for much advice and practical help. The apparatus is the subject of British Patent Application No. 38325/60, the rights of which have been assigned to the National Research Development Corporation.

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Direct-reading balances for percentage moisture content

by J. G. DOWNES, B.Sc., A.M.I.E.E., B. H. MACKAY, B.Sc., L. G. BELLAMY and V. D. BURGMANN, B.Sc., B.E., Commonwealth Scientific and Industrial Research Organisation, Wool Research Laboratories, Division of Textile Physics, Ryde, N.S.W., Australia

MS. received 25th August 1961

Abstract

This paper describes two types of balance which indicate per cent moisture content directly, and in which the initial sample weight may vary within wide limits. They have been designed primarily for measuring the moisture in wool at various stages in processing and for this purpose are used in conjunction with a hot-air drying apparatus. The same balances could be used to determine the percentage content of removable components in many other materials. An analysis of the principles of operation of the balances is given and experimental models are described.

Introduction

INDICATING balances which are directly calibrated in terms of moisture content of a sample are well known. In most of these balances the material under test is weighed out to a fixed amount. Often this is not done explicitly but by adjusting the amount of material to bring the pointer to a zero mark on the scale. The material is then dried either in a separate apparatus or on the balance (e.g. by radiant heating). As soon as drying is complete the balance indicates directly the percentage moisture in the original sample. Since no calculation is necessary, time is saved and the possibility of error is reduced.

In certain cases it is undesirable to have to adjust the amount of material to a precise value. For instance, in the time required to do this the moisture content may change appreciably, or the sample may be of a material such that its weight is not readily adjusted (e.g. a length of textile yarn). A direct-reading balance which does not require a fixed initial weight of material would frequently be of advantage. One balance has been described (Barker and Hedges 1926) which requires no fixed initial amount of material but it is not truly direct reading; to obtain the final result, division of one observed quantity into another is necessary. Another balance which is available commercially (Close and Marshall 1933) does not need an exact initial amount of material but requires an initial weighing and the manual setting of two sliding weights to particular values during the determination. This balance reads directly in moisture content.

This paper describes two types of balance which indicate percent moisture content directly and in which the initial sample weight may vary within wide limits. They are used in conjunction with a hot-air drying apparatus and have been designed primarily for measuring the moisture in wool at various stages of processing. The same balances could be used to determine the percentage content of removable components in many other materials.

The two types of balance may be described as using the principles of variable beam length and variable sensitivity.

In this work, moisture content is reckoned as a percentage of the dry weight of the material. In the textile industry

moisture content so expressed is known as *regain*. In cases where moisture content is expressed otherwise (e.g. as a percentage of the original weight) the general principles outlined remain valid but minor changes will be required in the analysis and in the calculation of scale laws.

The variable beam length balance

General description

Consider a pivoted beam (Fig. 1(a)) on which the position of the point of attachment of the sample container C is

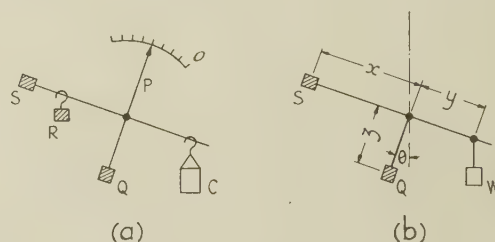


Fig. 1. The variable beam-length balance, (a) simplified arrangement, (b) notation for analysis of operation.

adjustable by a slide which may be moved along the beam. A counterweight R for the empty container is fitted to a similar slide on the opposite arm and a mechanical linkage ensures that R always counterbalances the container. A weight Q attached to a shaft perpendicular to the beam determines the balance sensitivity in the usual way. An additional fixed weight S is carried on the counterweight arm. The deflection of the beam is indicated by a pointer P on a scale. The position of the zero of the scale is approximately at one limit of the deflection range of the balance. To operate the balance, any convenient weight of the material under test is placed in the container, whose point of attachment is then adjusted along the beam until the pointer indicates zero. The sample is then dried and replaced on the balance, when the deflection indicates the initial regain directly.

Analysis of principle

Denoting the weight of the sample by W , the distances from the fulcrum of the weight S , the point of attachment of the can, and the weight Q by x , y and z respectively, and neglecting the weights of the pointer and container, since these are always counterbalanced, we may equate moments (see Fig. 1(b)) when the balance is at rest with the pointer at an angle θ from the vertical to give

$$(Wy - Sx) \cos \theta = Qz \sin \theta \quad (1)$$

$$Wy = Qz \tan \theta + Sx. \quad (2)$$

Since y is always adjusted initially to give the same deflection θ_i we have

$$W_i y = Qz \tan \theta_i + Sx \\ = K \quad (3)$$

where K is a constant and W_i denotes the initial weight of the sample.

If W_f denotes the weight of the sample after drying, we have from (1)

$$(W_f y - Sx) \cos \theta_f = Qz \sin \theta_f \quad (4)$$

where θ_f is the corresponding deflection.

Defining the fractional regain

$$M = \frac{W_i - W_f}{W_f}, \quad (5)$$

and eliminating W_i and W_f between Eqns (3), (4) and (5), and rearranging, we have

$$\tan \theta_f = \left(\frac{K}{1 + M} - Sx \right) / Qz. \quad (6)$$

Equation (6) shows that, since K , Q , z , S and x are constant for any particular balance, the deflection of the balance is a function of M only and does not involve the sample weight explicitly.

Thus the basic principle of the variable beam length balance is that all samples, irrespective of size, by a simple adjustment exert the same initial moment on the balance.

A given fractional change in weight of any sample (corresponding to a given value of regain) thus always produces the same change in moment and therefore the same deflection.

Experimental

An experimental balance has been built on the principle outlined (Fig. 2). The container support and the container

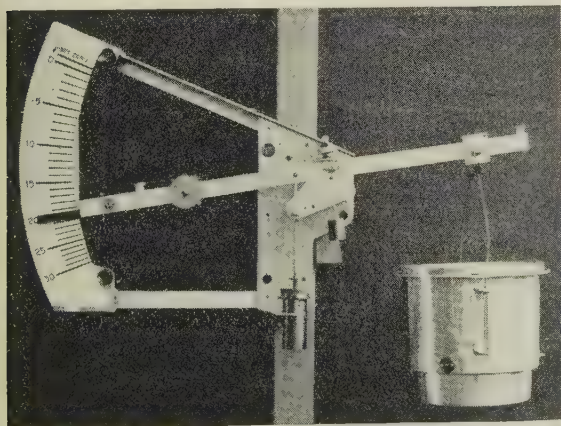


Fig. 2. Experimental model of variable beam length balance.

counterweight are carried on slides which travel on the balance beam. The slides are attached to opposite sides of a top of cable which passes around pulleys at the ends of the beam and which is driven manually by a capstan mounted at the centre of the beam. With this arrangement the slides

are always equidistant from the fulcrum. Knife edges are used at the beam fulcrum and at the point of attachment of the container. The pointer is an extension of one arm of the beam. Damping is by an oil dashpot.

The balance has been designed for sample weights in the range 100 to 350 g approximately. A value of sensitivity has been chosen such that a moisture content of 30% corresponds to an angular deflection of 42° . In practice the initial zero adjustment has been found easy to make and the balance performance has been satisfactory.

When the dried sample is replaced on the balance there is a small apparent loss of weight due to the container and contents being hot. In this balance the effect is compensated somewhat by biasing the zero. This method of compensation can be only a compromise since the apparent loss of weight varies in its influence depending on the position of the container along the beam.

The variable-sensitivity balance

General description

In its simplest form this balance consists of a beam, at one end of which is carried the container with the material under test, while at the opposite end is a mass to counterweight the empty container. The sensitivity of the balance is controlled by a weight which may be moved along an axis passing through the balance fulcrum. Fig. 3(a) shows in simplified form a balance of this kind.

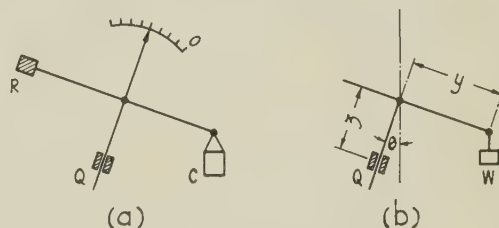


Fig. 3. The variable-sensitivity balance, (a) simplified arrangement, (b) notation for analysis of operation.

In operation the sample, of any convenient weight, is placed on the balance and the sensitivity weight Q adjusted along its shaft until a particular value of deflection is obtained. This deflection represents the zero point. By this adjustment the sensitivity is made inversely proportional to the initial weight of the sample. After drying the sample is replaced on the balance and the deflection from the zero point indicates the initial regain. The scale calibration is independent of the sample weight as the following analysis shows.

Analysis of principle

Referring to Fig. 3(b), if z denotes the distance of the sensitivity weight Q from the fulcrum and θ the angle of the axis of Q from the vertical, then the initial adjustment of Q ensures that

$$Qz \sin \theta_i = W_i y \cos \theta_i \quad (7)$$

where W_i = initial weight of sample and θ_i = initial deflection (zero point of scale). From (7)

$$W_i = \frac{Qz}{y} \tan \theta_i. \quad (8)$$

Similarly, if W_f = weight of sample after drying and θ_f = final deflection, then

$$W_f = \frac{Q_z}{y} \tan \theta_f. \quad (9)$$

Using the definition of the fractional regain M as given by Eqn (5), we have from (8) and (9)

$$M = \tan \theta_i \cot \theta_f - 1. \quad (10)$$

The deflection for a given regain depends only on the value of the initial deflection θ_i . Unlike the variable beam length balance, there are no other parameters by which the scale law or sensitivity may be adjusted.

In certain applications the sensitivity will be insufficient to provide an adequate scale length unless some form of scale magnification such as an optical lever is used. In these cases recourse may be had to a modified form of the balance in which the angle between the balance beam and the axis of the sensitivity weight is not 90° . By suitable choice of this angle and of the value of θ_i , substantial increases in deflection for a given value of M may be obtained over certain ranges of M . A variety of scale laws may also be obtained, some of which are advantageous in particular applications. The behaviour of this modified form of balance is analysed more fully in the Appendix.

Experimental

An experimental variable-sensitivity balance has been constructed in the modified form just described. The basic arrangement is as shown in Fig. 4(a), while Fig. 5 shows a

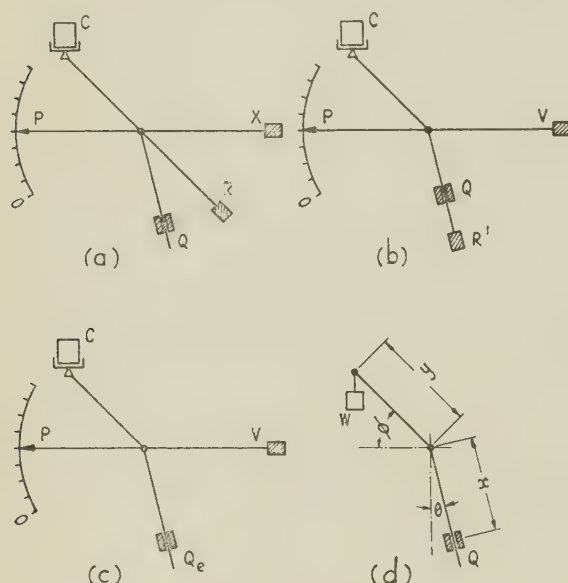


Fig. 4. Modified form of the variable-sensitivity balance, (a) simplified arrangement, (b) resolution of R into R' and part of V , (c) combination of R' and Q as Q_e , (d) notation for analysis of operation.

photograph of the balance. For convenience in use the pointer P has been placed in the position shown. It is counterweighted by part of the weight V (see Fig. 4(b)); the counterweighting of the container C is provided by the remaining part of V and part of the sensitivity-adjusting

weight Q_e (Fig. 4(c)) as shown in the Appendix. The angle between the beam (carrying the sample) and the shaft on which Q travels is 168° *, and the initial angular displacement of the Q -shaft from the vertical is 50° . The scale is calibrated from 0 to 100%; it is non-linear, being expanded at the lower end.

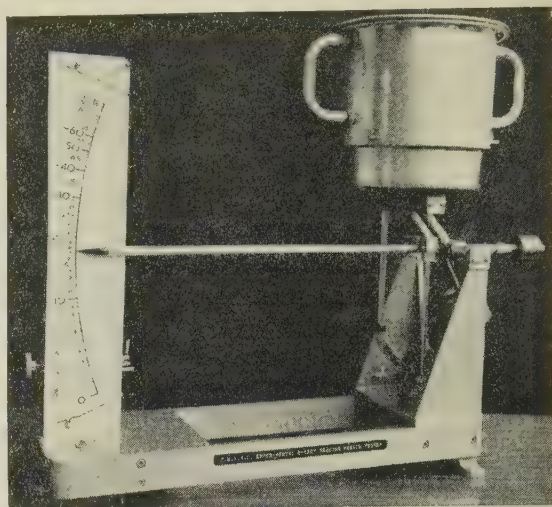


Fig. 5. Experimental model of variable-sensitivity balance.

where the greatest accuracy is required. For ease in placing the container on the balance and to eliminate swinging of the container, a platform with an associated parallel linkage is incorporated. Damping is provided by an oil dashpot. Steel knife edges in agates have been used at the main beam bearing and the platform bearing, while the joints of the parallel linkage and the dashpot link use polished steel pins in Teflon sleeves. The friction in the balance under the most unfavourable test conditions (represented in the present case by minimum load and slow unidirectional motion of pointer to rest) results in an error less than 0.25% of moisture content at the centre of the scale (15 to 20% moisture content).

Adjustment of the sensitivity weight can cause a certain amount of disturbance to the balance. The setting operation is simplified by the provision of a latch to restrict the movement of the balance during this operation. The latch, mounted on the scale, acts on the pointer tip and is released after the zero has been set.

The balance operates with samples between 150 and 800 g in weight.

An advantage of the variable-sensitivity balance over the variable beam length type is its simplicity of construction, and the ease of incorporating a parallel linkage to avoid oscillation of the container.

In this balance the apparent loss of weight due to the container and contents being hot is compensated by a weight which is disconnected from the platform during zero setting (container cold) but is automatically picked up as soon as the pointer deflects away from zero. The apparent loss is considered to be the sum of buoyancy and convection effects and its magnitude is determined empirically by cold and hot weighing of a can containing non-hygroscopic fibre.

These balances are subject of patent applications by the Commonwealth Scientific and Industrial Research Organization.

* This figure corresponds to a value of 78° for the angle ψ defined in the Appendix.

Appendix

Analysis of variable-sensitivity balance

The development of the balance may be followed by referring first to Fig. 4(a). The empty container and its pan are counterbalanced by R , and the pointer by X . The balance thus reduces essentially to that of Fig. 3(b) except that the beam and the Q -shaft are not necessarily perpendicular.

The design of Fig. 4(a) may be simplified by splitting the weight R into two components having an equivalent effect (see Fig. 4(b)). One component is added to X , which now is designated V . The other component, designated R' , is attached to the Q -shaft.

The position of the weight V is adjusted in the initial setting-up of the balance. When the Q -shaft is vertical the empty container and pointer must be balanced by V alone; the adjustment of V consists therefore of moving it until the Q -shaft is vertical.

Fig. 4(b) may be further simplified by combining Q and R' into one moving weight Q_e , which may be thought of as having a fixed component R' . This arrangement is illustrated in Fig. 4(c) and is essentially the form in which the balance has been built (Fig. 5).

For purposes of analysis the weight of the empty container and pointer together with the fixed counterweights V and R' (Fig. 4(b)) may be neglected, so that only the sample weight W and the sensitivity weight Q need to be taken into account (Fig. 4(d)). Let the distances from the fulcrum of the point of attachment of W and the centre of gravity of Q be y, x respectively. Let the angle of the beam from the horizontal be ϕ and the angle of the Q -shaft from the vertical be θ , being counted as positive in the directions shown.

Equating moments when the balance is at rest,

$$Wy \cos \phi = Qx \sin \theta. \quad (11)$$

Let ϕ_i, θ_i be the values of ϕ, θ for the zero position of the balance and W_i be the initial sample weight. Hence from (11)

$$W_i y \cos \phi_i = Qx \sin \theta_i. \quad (12)$$

Whatever the value of W_i, x is adjusted so that (12) is satisfied.

Similarly, if W_f is the value of the sample weight after weighing, and the corresponding values of ϕ, θ are ϕ_f, θ_f , we have

$$W_f y \cos \phi_f = Qx \sin \theta_f. \quad (13)$$

Q, x and y may be eliminated between (12) and (13) to give

$$\frac{W_i - W_f}{W_f} = \frac{\sin \theta_i \cos \phi_f}{\sin \theta_f \cos \phi_i} - 1 \quad (14)$$

$$= M \quad (15)$$

where M is the fractional regain (from (5)).

Now $\phi + \theta = \phi_i + \theta_i = \phi_f + \theta_f = \text{constant}$, ψ say. (16)

Putting (16) into (15) gives

$$M = \frac{\sin \theta_i \cos (\psi - \theta_f)}{\sin \theta_f \cos (\psi - \theta_i)} - 1 \quad (17)$$

which on reduction becomes

$$M = \frac{1}{\cot \theta_i + \tan \psi} (\cot \theta_f - \cot \theta_i). \quad (18)$$

Once the position of the scale zero has been fixed θ_i is fixed. This value and that of ψ are constant for a given balance design. Therefore the quantity outside the brackets in (18) is a constant for a given balance design, and the law of the scale is determined by the expression within the brackets. ψ may have any value but there are certain limitations on the range of values of θ if the centre of gravity of the balance as a whole is to lie vertically below the fulcrum. These may be summarized as follows:

For $-90^\circ \leq \psi < 90^\circ$, it is necessary that $90^\circ + \psi \geq \theta \geq 0$, and for $90^\circ < \psi \leq 270^\circ$, then $0 \geq \theta \geq -(90^\circ + \psi)$. The choice of the value of θ_i in the original design is restricted to these ranges.

The condition $\psi = 0$ represents the simple case of Fig. 3. For a given design, i.e. given ψ and θ_i , the calculation of the scale is made more convenient by rewriting Eqn (18) as

$$\tan \phi_f = \frac{\tan \phi_i + M \tan \psi}{1 + M}. \quad (19)$$

The deflection $\theta_i - \theta_f$ has been calculated from Eqn (18) for a number of values of θ_i and ψ and the results plotted against M in Fig. 6. It is found that for values of θ_i up to

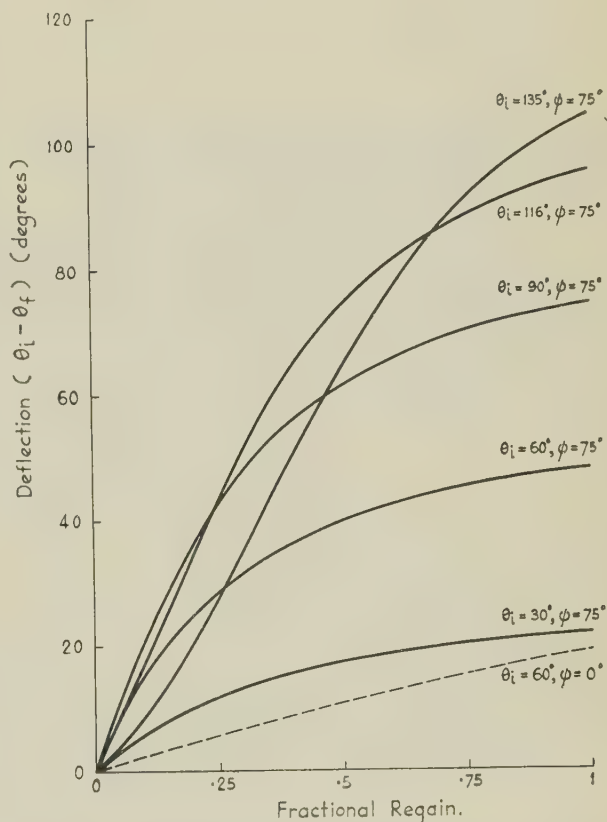


Fig. 6. Plots of deflection $\theta_i - \theta_f$ against fractional regain M for various values of θ_i and ψ for the modified form of variable-sensitivity balance.

about 116° the curve of $\theta_i - \theta_f$ against M is concave to the M axis. At higher values of θ_i an inflection appears. The curve for $\theta_i = 116^\circ$ is interesting in that there is a long nearly linear region of high sensitivity (steep slope); a linear scale over the range of M of 0 to 30% can be drawn with an error everywhere of less than 0.3% regain.

Consideration of Eqn (18) shows that the shape of the curve of deflection versus M does not depend on the value of ψ ; e.g., the $\theta_i = 116^\circ$ curve has a long linear region for any value of ψ . The effect of a change in ψ may be seen by comparing the curves for $\theta_i = 60^\circ$, $\psi = 75^\circ$ and $\theta_i = 60^\circ$, $\psi = 0$; the change merely alters the scale of the graph in the M direction.

In the case of the variable beam length balance also, modification of the scale law is possible by changing the angle between the beam and the Q -shaft (Fig. 1) from 90° to some other value. An analysis similar to the above may be applied.

References

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CLOSE, J. K., and MARSHALL, C. O., 1933, *Instruments*, 6, 113.

Note added in proof. Since the MS. was submitted for publication the attention of the authors has been drawn to British Patent 427193 which describes a balance embodying the principle of variable sensitivity discussed here.

Notes and Comments

1962 Annual Exhibition of The Institute of Physics and The Physical Society

The 1962 exhibition will be held in the Old and New Halls of the Royal Horticultural Society, Vincent Square, Westminster, London, S.W.1. It will be open at the following times and admission will be by ticket only.

Monday, 15th January	10.30 a.m.–7 p.m. (Members, Students, Subscribers and Group Subscribers of the Institute and Society, and Press only up to 2 p.m.)
Tuesday, 16th January	10 a.m.–9 p.m.
Wednesday, 17th January	10 a.m.–7 p.m.
Thursday, 18th January	10 a.m.–7 p.m.
Friday, 19th January	10 a.m.–1 p.m.

Applications for tickets should be sent to the Secretary of The Institute of Physics and The Physical Society, 47 Belgrave Square, London, S.W.1, enclosing a stamped, addressed envelope to take the tickets, which measure $4\frac{1}{2}$ in. by 3 in.

The Exhibition *Handbook*, which contains descriptions of exhibits and of some new devices for which space could not be allocated, will be published in mid-December. It is more than a catalogue and serves as a reference book throughout the year. The price is 6s. per copy (2s. 6d. to Members, Students and Subscribers), plus 2s. postage.

During the exhibition the following lectures will be given:

Tuesday, 16th January, at 5.45 p.m.

A physicist looks at music by Dr. C. A. Taylor (Manchester College of Science and Technology)

Thursday, 18th January, at 5.45 p.m.

The uses of elasticity in instrument design by Professor R. V. Jones (University of Aberdeen).

A leaflet giving abstracts of the above lectures and further information about the exhibition may be obtained from The Institute of Physics and The Physical Society, 47 Belgrave Square, London, S.W.1.

Measurement of rapid temperature changes by thermocouples

J. A. SIRS, Ph.D., Physics Department, St. Mary's Hospital Medical School, University of London, London, W.2

MS. received 10th July 1961, in revised form 16th August 1961

Abstract

Measurements have been made of the response time of thermocouples to sudden temperature changes. A simple circuit has been designed to further improve the response time, so that changes occurring within a few milliseconds can be observed with a mechanically robust junction.

Introduction

THERE are many applications in which it is desired to follow a rapid transient change in temperature. A chemical reaction, for example, can be examined by observing the heat generated in a stopped flow system, of the type used by Roughton (1934) and Chance (1940). The present experiments were designed to find what limitation the time lag of the thermocouple placed on these observations. The response of a thermocouple to an instantaneous change of temperature has been measured directly and the effect of the time lag reduced by incorporating a simple phase advance circuit in the amplifier.

Measurement of the thermocouple response time

An effectively instantaneous change in temperature has been obtained by discharging a condenser through a low resistance. A schematic circuit of the method is shown in Fig. 1. By closing switch S_3 , the 20 mF condenser C was

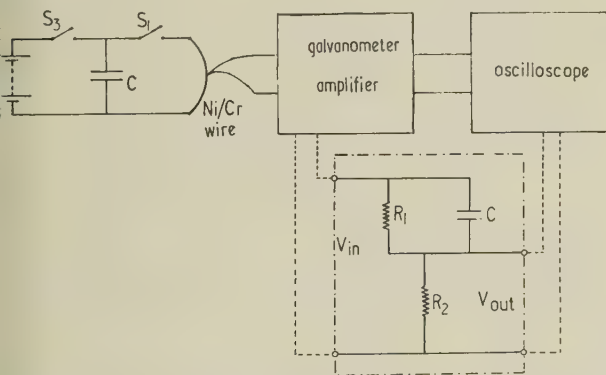


Fig. 1. Schematic circuit of measuring system and correcting network.

charged to 150 v, and then S_3 released again. The switch S_1 was now closed to discharge the condenser through 0.01 in. of Nichrome 34 s.w.g. wire of approximately 6.5 ohm resistance. The electrical discharge was over in a fraction of a millisecond and the energy is dissipated instantaneously as heat in the wire, suddenly raising its temperature by 1 deg c.

The thermocouple was bound to the Nichrome wire with cotton thread and connected to a galvanometer amplifier. The output was then displayed on a Cossor d.c. oscillograph and the trace recorded photographically.

The response curves of two typical thermocouples are shown in Fig. 2. The slower response was obtained with a

thermocouple made from 38 s.w.g. constantan and 40 s.w.g. copper, both covered by a silk insulation, and silver-soldered together. The fast thermocouple was from 46 s.w.g. standard

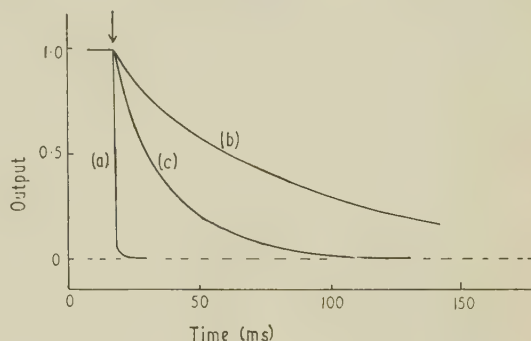


Fig. 2. Response curves to a unit step impulse applied at the time indicated by the arrow (a) of the amplifier only, to a voltage change, (b) of a 38/40 s.w.g. Constantan-copper thermocouple and (c) of a 46/46 s.w.g. copper-Eureka thermocouple to a 2° c temperature change.

enamelled copper wire soldered to 46 s.w.g. Eureka with 'Fryolux' solder paint. Even with this latter thermocouple the response time was of the order 15 ms, some five times slower than the desired speed. This could have been achieved by making the thermocouples of still finer wire but as they were already very thin, and mechanically quite easily broken,

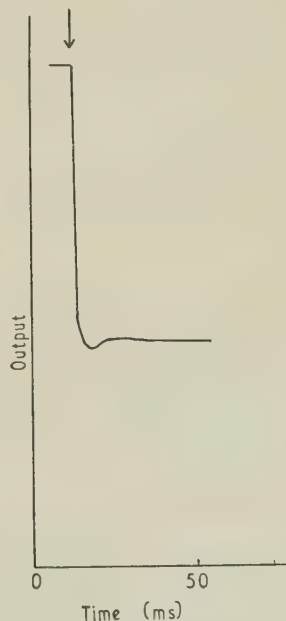


Fig. 3. Response curve to a unit step impulse applied at the time indicated by the arrow of the 46/46 s.w.g. copper-Eureka thermocouple with the correcting network connected.

it was decided to obtain the extra performance by a compensating circuit in the amplifier.

Improvement of the response time by circuit design

To a first order of magnitude the thermocouple response to a unit step impulse can be represented by a waveform $(1 - e^{-t/T})$, and its Laplace transform $1/p(1 + pT)$, where T is the time constant.

The signal can now be passed through an additional phase advance circuit, indicated in Fig. 1, whose transfer function is

$$\alpha \left(\frac{1 + pT'}{1 + pT'\alpha} \right),$$

where $T' = R_1 C$ and $\alpha = R_2 / (R_1 + R_2)$.

If we match the circuit to the thermocouple, i.e. make $T = T'$, the overall transfer function becomes $\alpha/p(1 + pT\alpha)$ and the output waveform to a step input $\alpha(1 - e^{-t/\alpha T})$. The time constant has been reduced by a factor α at the expense of a similar reduction in amplitude. A limit to the value of α is set by the second-order terms of the equations becoming significant and introducing oscillatory overshoot.

Taking $T = 15 \times 10^{-3}$, from the curve for the 46/46 copper-Eureka thermocouple in Fig. 2, a suitable ratio of R_1 to R_2 was chosen and C was calculated to meet this condition. A typical example of the improvement obtained is shown in Fig. 3.

References

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ROUGHTON, F. J. W., 1934, *Proc. Roy. Soc. B*, **115**, 473.

Notes and Comments

Journal of Catalysis

We have received notice of the new *Journal of Catalysis*, which is to be published by Academic Press, 111 Fifth Avenue, New York 3. It is to be a medium of publication for all original scientific studies in heterogeneous catalysis, as well as subjects related to homogeneous catalysis. Studies relating catalytic properties with chemical processes at surfaces, including the study of surfaces by various physical means, will be included in the scope of this journal, as will molecular rate processes and studies of the chemistry of surfaces.

The Editors will be Professor J. H. de Boer, Technological University of Delft and Professor P. W. Selwood, Northwestern University. The first issue is expected to appear early in 1962.

British Standards

We have recently received the following British Standards: B.S. 526: 1961, Definitions of the calorific value of fuels; B.S. 1193: 1961, Specification for sizes of sensitized materials for recording instruments; B.S. 1928: 1961, Specification for gramophone records and reproducing equipment.

These are available, price 6s., from British Standards House, 2 Park Street, London, W.1.

Magnesium Data Book

We have received a copy of the revised edition of the *Magnesium Data Book* which is published by Magnesium Elektron Ltd. It is a compendium of useful facts about magnesium with special reference to their 'Elektron' Alloys.

Copies may be obtained from Magnesium Elektron Ltd., 5 Charles II Street, St. James's, London, S.W.1.

Conference on the Importance of Electricity in the Control of Aircraft

A Conference on the Importance of Electricity in the Control of Aircraft is being organized by a Joint Committee of The Institution of Electrical Engineers and the Royal Aeronautical Society and will be held in London on 26th, 27th and 28th February, 1962.

About 30-40 papers will be presented and the subject matter will be sufficiently wide to interest aircraft and equipment designers and specialists in all fields of aircraft electrical and electronic development. The emphasis will be on system design and methods of achieving the required reliability for these systems.

Further information may be obtained from the Secretary, The Institution of Electrical Engineers, Savoy Place, London, W.C.2.

International Conference on Magnetic and Electric Resonance and Relaxation

An International Conference on Magnetic and Electric Resonance and Relaxation will be held under the auspices of the Netherlands Physical Society and the Groupement Ampère from 2nd-7th July, 1962, at Eindhoven, The Netherlands. The subject will be mainly double resonance experiments but also nuclear magnetic resonance, electron spin resonance, dielectric relaxation, quadrupole resonance and related subjects. Abstracts must be submitted by 1st January, 1962.

Further information may be obtained from the secretary of the committee, Dr. D. J. Kroon, Philips Research Laboratories, Eindhoven, The Netherlands.

Method for obtaining minimum noise in a general purpose hot wire amplifier

by G. N. V. RAO, Department of Aeronautical Engineering, Indian Institute of Science, Bangalore 12, India

MS. received 27th June 1961

Abstract

It has been shown that the conventional practice of designing a compensated hot wire amplifier with a fixed ceiling to floor ratio results in considerable and unnecessary increase in noise level at compensation settings other than optimum (which is at the maximum compensation at the highest frequency of interest). The optimum ceiling to floor ratio has been estimated to be between $1.5-2.0 \omega_{\max} M$. Application of the above considerations to an amplifier in which the ceiling to floor ratio is optimized at each compensation setting (for a given amplifier band-width), shows the usefulness of the method in improving the signal to noise ratio.

It is well known that whenever compensation is introduced in a hot wire amplifier, to compensate for the thermal lag, considerable increase in noise level results due to the amplification of the noise frequencies. This difficulty has been particularly felt when measuring low values of turbulence, where signal strengths of the order of $20 \mu\text{v}$ are encountered. In such cases, it has been the practice to follow one of, or a combination of, the following procedures:

- (i) cutting out the compensation and using the finest wire available;
- (ii) reducing the band-width of the amplifier;
- (iii) using an input transformer, even though the use of any reasonably sized input transformer will affect adversely the low frequency signals of less than 10 c/s which have considerable energy.

The amount of increase in the noise level depends, in general, on the amount of compensation, band-width of the amplifier, and the ceiling to floor ratio of the compensation network (Kovaszny 1954). It has been the practice in recent times, as far as the author is aware (Kovaszny 1954, Shuh and Walker 1955), to build amplifiers with variable frequency band-width and fixed ceiling to floor ratio. The ceiling to floor ratio is adjusted to provide satisfactory amplification up to the highest frequency of interest, and for the maximum compensation expected to be used (Kovaszny 1954). The result has been that this ceiling to floor ratio is too high at lower compensation settings.

This state of affairs is illustrated in Fig. 1 where CD is the required ceiling for the nominal compensation beginning at f_a . However, it is clear that CD is too high for the nominal compensation beginning at f_b , the level at C'D' being ample. Thus if one maintains the ceiling at CD and sets the compensation of f_b , one will be unnecessarily amplifying 'extra' noise beyond the upper frequency of interest. It is, therefore, logical to enquire whether simultaneous variation of compensation and ceiling to floor ratio (to the optimum value),

will improve the signal to noise ratio of the amplifier to a useful degree.

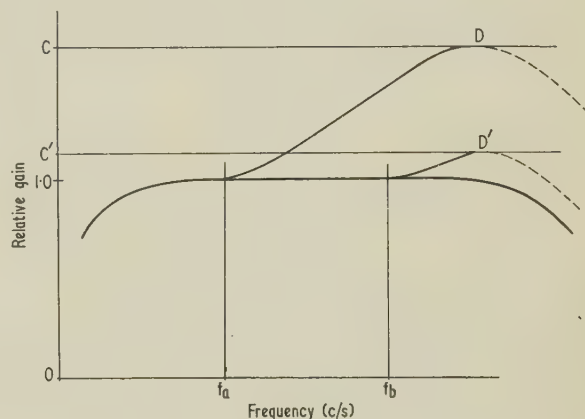


Fig. 1. Response of an amplifier to compensation.

This has been attempted in the twin channel hot wire amplifier built in this Department. It is proposed to use the amplifier only in low-speed wind tunnels, and the compensation network of Kovaszny (1954), involving feedback over two stages of amplification, has been used. In this network, variation of the ceiling to floor ratio K is best accomplished by varying the feedback resistance (R_3 in Fig. 17 of Kovaszny (1954)).

Not much information is available on the optimum ceiling to floor ratio for a given compensation setting. Kovaszny seems to suggest* the criterion $K = \omega_{\max} M_{\max}$, where $\omega_{\max}$ is the maximum circular frequency of interest in radians per second, and $M_{\max}$ is the maximum compensation in seconds, expected to be used. This criterion is not quite satisfactory near the upper frequency, 1.5 to 2.0 times the above value being more satisfactory.

The results are shown in Fig. 2 where the usefulness of controlling the ceiling to floor ratio is apparent. It is evident that choosing K according to the above criterion, one can obtain a reduction of as much as a third in the equivalent input noise level, if the amplifier is required to be suitable for a compensation range of 0.2-1.0 ms. With even twice the above value of the ceiling to floor ratio ($K = 2 \omega_{\max} M_{\max}$), useful reduction in the equivalent input noise level can still be obtained without in any way affecting the frequency

* It would appear from Kovaszny that whatever the procedure adopted for specifying K , $K = 300$ was thought to be desirable. The above criterion gives, for a maximum compensation of K of one millisecond and 50 kc/s band-width, $K = 314$. The actual value of $K = 250$ claimed to have been used (no measurement of K being reported in the paper) is probably due to consideration of the stability of the feedback network.

characteristic of the compensation. The whole scheme is most advantageous when very fine wires are being used

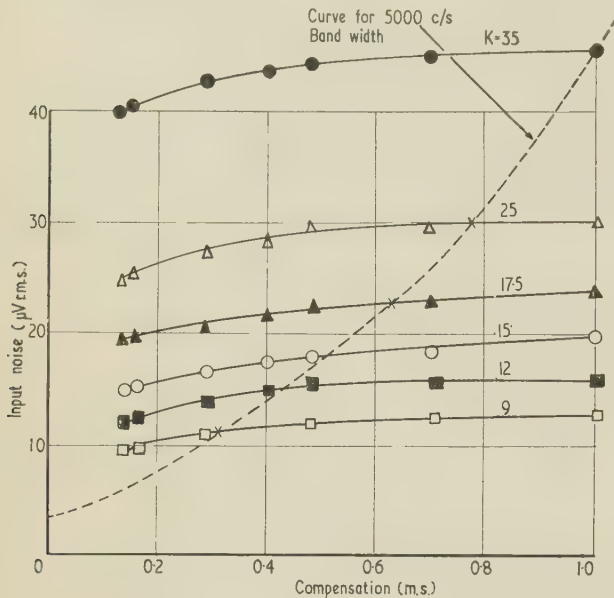


Fig. 2. Effect of ceiling to floor ratio on input noise level.

with a general purpose compensated amplifier that can be used with wires of several sizes. Using the same criterion mentioned above for K , we have also drawn on Fig. 2 a curve passing through points of correct ceiling to floor ratio for each compensation setting. The band-width of the amplifier was 5000 c/s throughout.

There are, however, two main factors to be carefully considered in the above scheme, namely, the stability of the feedback system and the variation of the frequency response of the amplifier.

It can be shown easily that if the amplifier is stable at the highest value of the ceiling to floor ratio, its stability will be even better at other lower values. On the other hand, the variation in the frequency response has to be more carefully considered, particularly the humping that takes place at the low and high frequency ends of the band. By suitable design, one can shift the hump at the high frequency end to well beyond the frequency of interest and the hump at the low frequency end to very close to the minimum low frequency of interest at all settings of the ceiling to floor ratio. Then it is a matter of incorporating suitable variable (varying with ceiling to floor ratio) filters or attenuators in the following stages, to level out the humps considerably. In the amplifier built in this Department, the response is flat within 2% from 3.5–5000 c/s.

Acknowledgments

The author is grateful to Professor Dhawan who initiated this project and has been a source of great encouragement both to the author and his colleague, Mr. V. S. Rajamani, who produced the detail design of the amplifier.

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Safe universal mounting and alignment system for X-ray goniometers

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MS. received 28th July 1961

Abstract

A universal system which permits all the goniometers in a particular x-ray laboratory to be positioned rapidly and simply on any x-ray generator is described. An integral part of the system is a 'dummy' x-ray tube—an optical system producing a beam of light—which permits the alignment of a goniometer to be carried out in complete safety from radiation. On transferring the goniometer to the x-ray generator no further adjustment is necessary.

The system improves the efficiency of a laboratory in which many workers use the same goniometers and generators. It also improves the safety from radiation, particularly for teaching laboratories in which alignment of goniometers has to be carried out by relatively inexperienced personnel.

1. Introduction

THE necessity for a universal system of mounts which will permit the rapid transfer of goniometers from one x-ray generator to another arises particularly in large laboratories used by many different workers. If some of these are inexperienced students the need is made more urgent by the safety requirements; a dangerous degree of scattering of radiation may occur during alignment procedures if they are not skilfully and quickly performed. If, in addition, the goniometers are of different types, with different bases, and the x-ray generators are also different, such a universal system, though inevitably elaborate, is even more desirable.

This was the problem which faced the authors a year or two ago, and the paper describes the solution that has been adopted. It has now been in use for about a year and has met with the approval of those who use it. In addition, various visitors have expressed interest in the system and it was felt worth while, because of this, to publish the details.

2. Basic principle

The fundamental principle is simple. The largest goniometer (in our case the 'Leeds' Weissenberg) was selected as the basis of the system, and the stands at each x-ray set were designed to fit it. All other goniometers were then fitted with 'intermediate' stands which—rather in the manner of an electric adaptor plug—receive the feet of the goniometer and in turn fit the stand so that the x-ray-beam axis of the camera always has the same position relative to the stand as that in the largest goniometer. A standard 'jig' is also made which permits the alignment of all the stands relative to the x-ray beams (notice that the system still works whatever the angle of emergence of the x-ray beam) (see Fig. 1).

The next requirement is a 'dummy' x-ray tube which consists of a simple optical system producing a beam of light, and a goniometer stand. The jig is used to adjust this stand so that the light beam bears the same relationship to it as that of the beam to the stands on the x-ray generators.

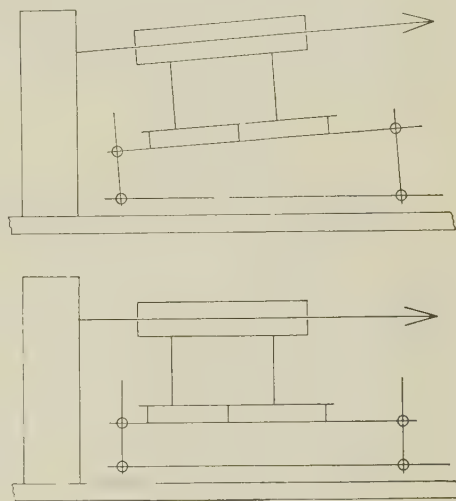


Fig. 1. The alignment system works for any angle of emergence of the x-ray beam.

Goniometers with their intermediate stands may then be completely aligned (and, incidentally, checked for internal alignment and adjustment) in perfect safety on the optical system, and then transferred to any x-ray tube without further adjustment.

3. Special requirements

It is obviously convenient if goniometers can be moved towards and away from the x-ray generator without disturbing the alignment. For this reason a 'groove and plane' kinematic system was chosen. It must be stressed, however, that this is only satisfactory if the groove is accurately parallel with the beam—a requirement which sometimes seems to be ignored (see Fig. 2).

Even when the alignment is good and the goniometer is moved close to the generator, some method of preventing scattering of radiation is required. We have adopted a slightly modified form of the 'labyrinth' trap first described by Kennard, Martin and Woodget (1959) and radiation-monitor tests have shown that the combination of the



Fig. 2. Unless the groove and plane are parallel to the x-ray beam the camera axis only coincides with the beam for one position on the slides.

precision alignment system with the labyrinth trap gives complete safety.

4. Details of the system

4.1. *The goniometer stands.* Each stand consists of a sheet of $\frac{3}{8}$ in. aluminium alloy, 24 in. $\times$ 12 in., carrying a flat strip A and a 'V-groove' strip B parallel to its short sides (Fig. 3). The V-grooves extend about 2 in. beyond the plate at each end.

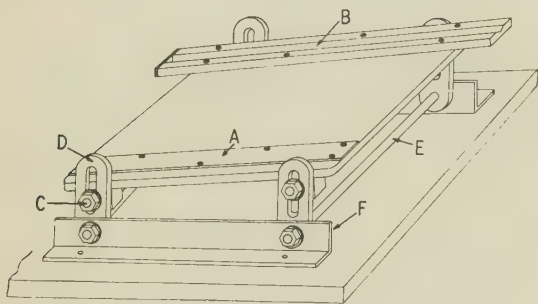


Fig. 3. A goniometer stand.

The plates are fitted with four $\frac{1}{2}$ in. Whitworth studs C which pass through four slotted links D which in turn are mounted on two steel rods E. The plate may thus be adjusted in height and in angle of tilt. The steel rods are held parallel to each other and fixed to the table by two angle strips F.

4.2. *The intermediate stands.* The intermediate stands consist of aluminium alloy sheets 22 in. $\times$ 12 in. with three feet A on the under-side which fit the groove and plane of the goniometer stand and permit the intermediate stand to slide parallel to the main stand (Fig. 4).

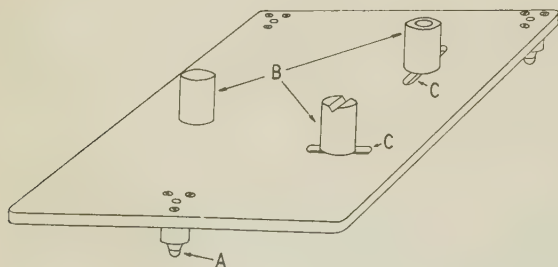


Fig. 4. An intermediate stand.

On the upper surface of the intermediate stands are mounted three $1\frac{1}{2}$ in. diameter pillars B, of a height to suit the individual goniometer and in such a position that when the goniometer is stood on them its axis is parallel to the feet which fit the groove of the main stand. The three pillars have respectively a conical hole, a V-groove, and a flat plate to give kinematic support to the feet of the goniometer. Two of the three pillars are fixed to the intermediate plate via slots C, so that adjustment of the feet position may be made during initial alignment. Once this has been done for a particular goniometer and intermediate stand, since they are only used together, it is rarely necessary to make this adjustment again.

4.3. *The standard jig.* The standard jig (Fig. 5) consists of a tube 1 in. in diameter and about 10 in. long. This is

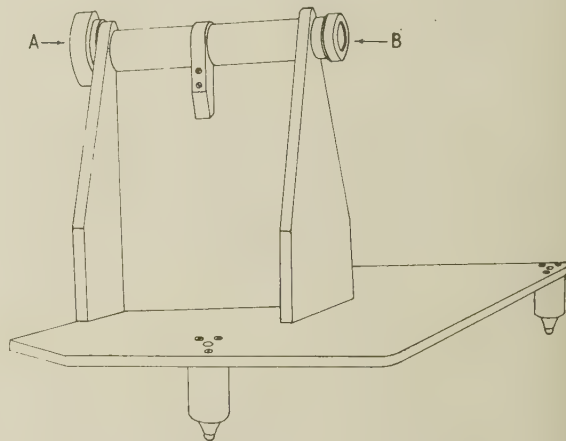


Fig. 5. The standard jig.

mounted on a plate exactly like an intermediate stand. The tube is mounted very rigidly and at such a height that its axis bears the same relationship to the groove of the goniometer stand on which it is placed as that between the x-ray axis of the Leeds Weissenberg goniometer and its stand.

At the front end of the tube A is the part of a labyrinth trap usually fitted to a goniometer and it is closed by a metal disk with a small pin-hole (0.5 mm diameter) at its centre. At the other end B one of two caps with either a ground glass screen and a cross wire or a fluorescent screen with a cross may be pushed on.

4.4. *The 'dummy' x-ray tube.* The dummy x-ray tube (Fig. 6) consists of a projector lamp with integral reflector A, focused on to a hole about 1 mm in diameter at one end of a tube B. At the other end C is a larger hole which may be

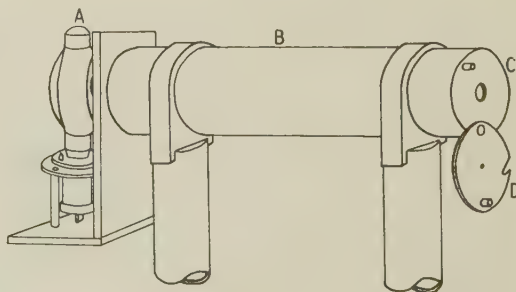
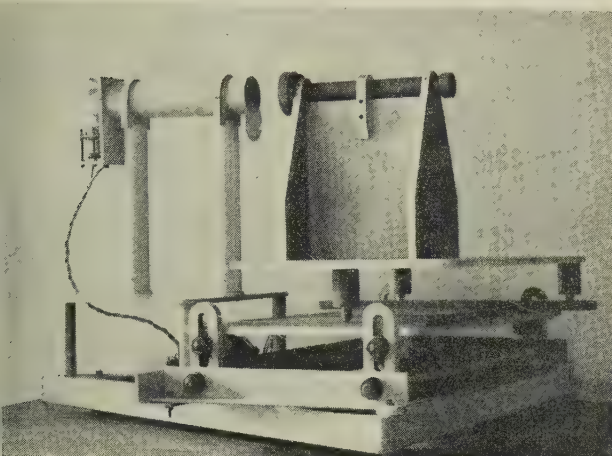
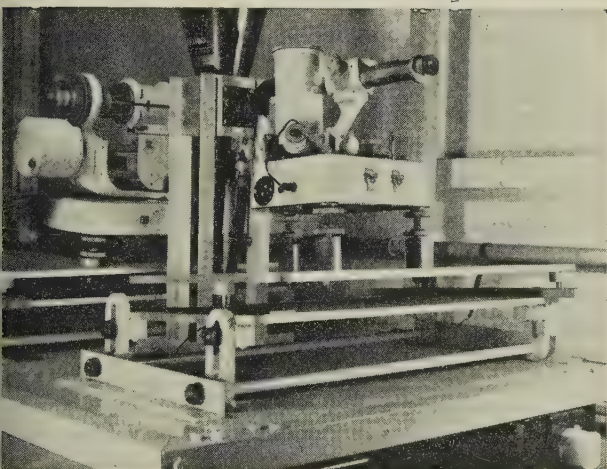


Fig. 6. The 'dummy' x-ray tube.

duced to pin-hole size by a pivoted plate D. The larger plate is used in the earlier stages of alignment and the pin-hole later. A stand identical with those fitted to the x-ray generators is fitted to the dummy x-ray tube, and it is, of course, important that the axis of B should be at least as high above the stand as the maximum existing on any of the generators.



(a)



(b)

Fig. 7. (a) The standard jig in position on the 'dummy' x-ray generator. (b) A goniometer in position on its intermediate stand drawn back on the groove and plane to show the labyrinth trap.

5. Sequence of operations

The dummy x-ray tube and a goniometer stand are set up in a permanent position and the height and inclination of the stand are set by placing the standard jig on the stand and adjusting until the light spot observed is central and of maximum intensity. The goniometer stands on the x-ray generators are then adjusted in a similar way (using, of course, a fluorescent screen, backed by thick lead glass, for observation on the end of the tube of the jig).

The light beam in the dummy x-ray tube and the x-ray beams from all the generators now bear the same relationship of height and orientation to the goniometer stands.

A goniometer may then be placed on its intermediate stand and then on the goniometer stand of the dummy x-ray tube. *Without readjusting* the goniometer stand, but using the adjustments on the intermediate stand and on the goniometer feet, the light beam is made to pass along the goniometer axis. (Before removing the goniometer various internal adjustments of the goniometer itself may be made. For example, a check on the intersection of the beam axis and the crystal rotation axis and on the angle between them.) The goniometer, complete with intermediate stand, may now be placed on any x-ray generator without readjustment.

Photographs of the standard jig in position on the dummy x-ray tube and of a goniometer mounted on an x-ray generator (drawn back to show the labyrinth trap) are given in Fig. 7.

6. Conclusions

As a result of a year's experience of the operation of this system we feel that it is well worth the trouble involved in installation. The safety of the whole laboratory from radiation hazards is greatly improved; the convenience of the change from one x-ray source to another gives a valuable saving in time; the training of new research students in the use of x-ray equipment is simplified. Perhaps the most interesting result, however, is that attention is drawn to the importance of accurate alignment, both internal and external, and if alignment is made simple it is much more likely to be carried out.

Acknowledgments

At various stages helpful discussions were held with our colleagues in the Department of Physics, and Mr. J. C. Collins, of the Municipal Engineering Department, made the scattered-radiation tests on the completed equipment.

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Shock tube beta-ray densitometer

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Abstract

A method for measuring the varying density behind a hypersonic shock wave in air using the absorption of β -particles is described. Calculated absorption curves are given for typical β -ray energies over the full range of initial downstream pressures encountered in shock tubes.

The scintillator, photomultiplier, detector circuit is discussed and an illustrative calculation of source size and accuracy of measurement is given for the case of ^{35}S .

1. Introduction

THERE are several methods of varying complexity and accuracy available for the measurement of gas density in the shock tube, the commonest being the use of the Mach-Zehnder optical interferometer (see Ladenburg and Bershader 1955). This requires expensive optical flats and windows and also is mechanically and thermally sensitive; furthermore, the interferometer usually needs much ancillary recording apparatus if density time resolution is required. One distinct limitation is that its useful density range is restricted to a lower level of about a few millimetres of mercury at room temperature, because at these lower gas densities the optical path differences involved are too small to be detectable.

This low density limitation has led to the development of other techniques, e.g. Grun *et al.* (1953) developed an electron accelerator which gave a parallel beam of monoenergetic electrons of several kiloelectron volts energy. This beam probed the gas under investigation and became scattered and absorbed. The instrument was qualitative and acted like an electron beam shadowgraph in gases whose pressures ranged from 30 to 10^{-3} mm Hg at room temperature for electrons of 50 kev. This idea of using an electron beam technique was further developed by Venable and Kaplan (1955) who studied the quantitative scattering of the beam. In the gas density range considered by these workers the electron transmission through the gas varied exponentially. This is not always true for a monoenergetic electron beam (see Evans 1955). Certain criteria must be satisfied and these are discussed by Ballard and Venable (1958), who show that a careful design of electron gun must be made in order that the beam intensity and electron total scattering cross section are sufficiently great to enable a statistically significant attenuation experiment to be made. Duff (1959) describes a shock tube density measurement using this type of electron gun.

2. Physical principles of the densitometer

Clearly this electron beam attenuation approach could be extended, in principle, over the whole range of gas densities obtainable in the shock tube. However, the design of such

a versatile electron gun would be difficult. As an alternative it is suggested that β -rays emitted by a radioactive source could be used. It is well known that β -ray spectra are not monoenergetic, but are continuous up to a certain maximum value of energy $E_{\max}$. The absorption curve of β -particles is quite closely an exponential function, i.e. the fractional transmission decreases exponentially over a certain range of absorber thickness and finally drops away to zero when the absorber thickness equals the maximum range of the β -particles (Evans 1955). We can therefore write the β -ray attenuation in a medium in the form

$$I_x = I_0 \exp(-\mu x) \quad (1)$$

where I_0 is the initial intensity and I_x the final intensity of the β -rays after passing through a medium of thickness x characterized by an apparent linear absorption coefficient μ .

If ρ is the density of the absorbing medium, then experiment shows that the mass absorption coefficient μ/ρ is practically independent of the atomic weight A of the absorbing medium and rises only slightly with increasing atomic number Z ; it is, however, strongly dependent on $E_{\max}$ (Evans 1955). Various empirical formulae have been given expressing the mass absorption coefficient in terms of $E_{\max}$ for a particular β -ray spectrum and these are reviewed by Katz and Penfold (1952). For the calculations in this paper it will be sufficient to use the simple result given by Evans (1955), which is certainly applicable over a β -energy range of 0.1 to 3.0 Mev, viz.,

$$\mu/\rho = 17/E_{\max}^{1.14} \quad (2)$$

Here μ/ρ is in square centimetres per gramme of absorber and $E_{\max}$ is in mega electron volts. More elaborate expressions for the mass absorption coefficient do exist but need not be used, since it must be remembered that β -ray absorption is only approximately exponential. This is no limitation of the densitometer since it can readily be calibrated *in situ* under static conditions by merely adjusting the gas pressure downstream of the diaphragm. Table 1 gives values of the mass absorption coefficient for various values of $E_{\max}$.

Table 1. Values of mass absorption coefficient

$E_{\max}$ (MeV)	0.1	0.2	0.3	0.7	1.0
μ/ρ (cm ² /g)	234	107	67	26	17

3. Gas variables encountered in shock tubes

Two of the commonest gases studied in the shock tube are air and argon—the former for aerodynamic and chemical studies and the latter for spectroscopic studies as well as the physics of collisional ionization behind strong shock waves. Under hypersonic conditions (when the shock Mach number

ceeds about 5) the shock compressed gas no longer behaves as an ideal perfect gas but shows caloric imperfections due to molecular vibration, dissociation, electronic excitation and ionization.

Calculations of real gas properties using quantum statistical mechanics have been made for the commoner gases and several workers have compiled charts and tables of the change in the thermodynamic state variables in both air and argon. Feldman* (1957) has discussed air up to Mach 22 whilst Resler, Lin and Kantrowitz (1952) have discussed argon up to Mach 18 (see also Frood 1956, Radar search Establishment Memo 1305). The tables for argon show that in the Mach number range of 6–20, the density ratio varies between 2 and 14 for downstream pressure variations of 0.1 cm to 40 cm of mercury. The results for air encompass this range of parameters, so it will be sufficient to discuss the case of air in detail; any conclusions for air will hold for argon.

Another associated use for the densitometer is the study of relaxation processes behind hypersonic shock waves, the finite time elapsing as energy is passed from one internal mode of a gas molecule or atom to another mode. The Mach-Zehnder interferometer has been applied to study such relaxation processes (Blackman 1956, Matthews 1959) but as remarked above, this requires extensive ancillary time-resolving equipment. The proposed densitometer will simplify this problem. One parameter that will increase as the shock Mach number increases is the degree of ionization behind the shock. The presence of an increasing free charge density will not, however, significantly affect the β -rays as we shall now see. Nuclei are essentially transparent to electrons and any mutual interaction that occurs is confined to the longer range electrostatic field between the electron and the screened nucleus for the case of the neutral gas. For slow electrons the classical collision theory of Rutherford scattering is valid, i.e. the intensity of scattering varies as the inverse fourth power of the sine of the semi-scattering angle, showing that the vast proportion of the scattering will be at very small angles of a few degrees. For relativistic electrons (such as the β -rays considered here) the Rutherford theory breaks down and we must use the relativistic wave mechanical theory of Mott (see Evans 1955). This analysis shows that the Rutherford differential scattering cross section is substantially correct for small values of scattering angles, but for large scattering angles the Mott theory gives an even smaller cross section than the Rutherford theory, thereby accentuating the small angle effect described above. The net effect of ionization will be effectively to replace the partially screened nuclear field of the neutral atom by an approximate Coulomb field. The β -ray scattering by these free charges will be of very small angle, which in view of the large dimensions of the β -source and detector will not significantly affect the β -ray flux accepted by the detector.

4. Calculation of absorption occurring in the gas

The absorption to be expected behind hypersonic shock waves in air can readily be determined. We have, using eqn (1),

$$I_n(I_0/I_w) = \mu t.$$

where I_0 = β -ray intensity emerging from the radioactive source, I_w = β -ray intensity incident on to the detector

Hypersonic Gas Dynamic Charts for Equilibrium Air, AVCO Research Laboratory Report.

window after having passed through the gas, t = thickness of the gas sample, in this case the diameter of the cylindrical shock tube.

Using standard shock tube nomenclature, where suffix 1 refers to conditions ahead of the advancing shock wave and suffix 2 refers to conditions behind the shock wave, we have

$$\mu t = \frac{\mu}{\rho} \rho_2 t = \frac{\mu}{\rho} \frac{\rho_2}{\rho_1} \rho_1 t.$$

Using the values of ρ_2/ρ_1 corresponding to Mach number at various values of initial downstream pressure p_1 (and therefore density ρ_1) given by Feldman,* together with selected values of the mass absorption coefficient given in Table 1, we can calculate the ratio I_w/I_0 as a function of shock Mach number for various values of p_1 and $E_{\max}$. Figs 1, 2 and 3

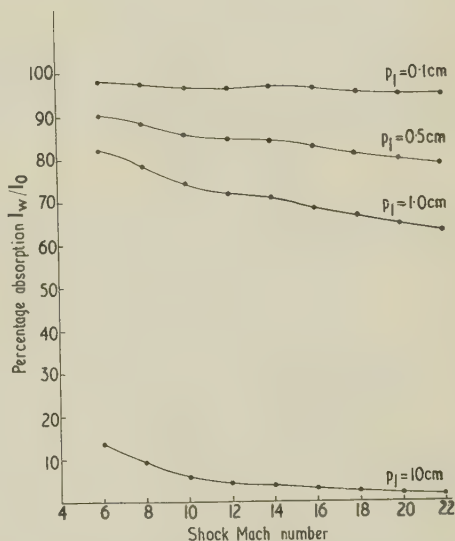


Fig. 1. Percentage absorption of β -ray intensity in air behind shock wave versus shock Mach number for various values of p_1 . $E_{\max} = 0.1$ mev.

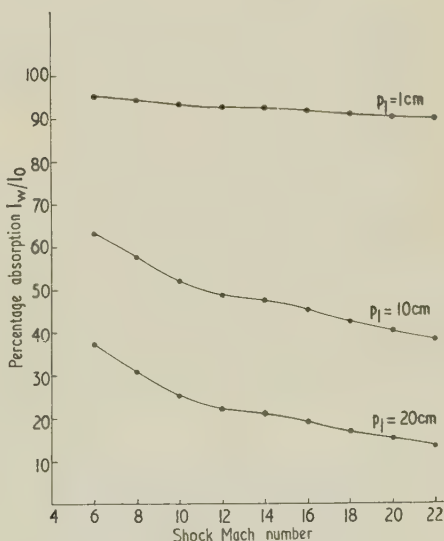


Fig. 2. Percentage absorption of β -ray intensity in air behind shock wave versus shock Mach number for various values of p_1 . $E_{\max} = 0.3$ mev.

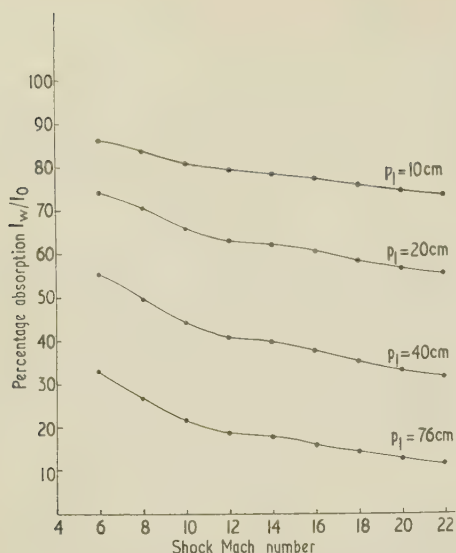


Fig. 3. Percentage absorption of β -ray intensity in air behind shock wave versus shock Mach number for various values of p_1 . $E_{\max} = 0.7$ mev.

show the attenuation to be expected. Clearly with the choice of p_1 and $E_{\max}$ the densitometer is capable of operating over a very wide range of shock tube conditions.

5. Choice of β -ray detector

The choice of the detector is largely governed by the number of counts necessary to obtain a reasonable accuracy. It was remarked above that the densitometer must be capable of resolving the relaxation zones behind the shock wave (with the possible exception of the translational shock front structure). Gas flow velocities behind hypersonic air shocks are given by Feldman and are several millimetres per microsecond. Now radioactive decay is governed by Poisson statistics, and if we wish to achieve a standard deviation of 5% then we must register 400 counts. If these counts are integrated in a circuit of time constant of $2 \mu\text{s}$, then the count rate is 2×10^8 counts per second. Such a high rate will require the use of a scintillator, photomultiplier, integrating circuit technique. Birks (1953) has shown that the total electric charge Q appearing at the anode load of the photomultiplier due to a particle of energy $E_{\max}$ being incident on the scintillator is

$$Q = \frac{E_{\max} f C_{ip} T_p G C_{pe} R(\nu_p) e \phi}{E_p} \quad (3)$$

where f = fraction of energy $E_{\max}$ dissipated in the scintillator, C_{ip} = efficiency of the scintillator in converting the energy of the β -particle into quanta, T_p = optical transparency of the scintillator, G = geometrical collecting power of the detector, C_{pe} = photoelectric conversion efficiency of the cathode, $R(\nu_p)$ = relative response at the phosphor peak frequency ν_p , e = charge on the electron, ϕ = overall gain of the photomultiplier, E_p = energy of the photons produced in the scintillator.

Scintillators and the characteristics of photomultipliers developed especially for scintillation counting are reviewed by Mott and Sutton (1958). If we use a thick scintillator with proper reflecting coating, such that all the energy $E_{\max}$ is dissipated, then $f = 1$. A suitable fast phosphor is polystyrene with a decay time of 2 ns, coupled with an RCA type 5819 photomultiplier which has the following character-

istics: $C_{ip} = 0.01$; $T_p = 1$ for an optically transparent system; $C_{pe} = 0.08$; $R(\nu_p) = 0.9$; $\phi = 5 \times 10^5$; $E_p = 2.5$ ev. If the stray capacitance of the photomultiplier anode load is C , then the voltage developed across this load for a single β -particle incident on to the phosphor is $V = Q/C$. Using Eqn (3), and taking $e = 1.59 \times 10^{-19}$ coulombs, $C = 10$ pf, gives

$$V = 2.3 \times 10^{-6} E_{\max} G \quad (4)$$

where V is in volts and $E_{\max}$ is in electron volts.

The flux of β -particles on to the scintillator will result in a continuous voltage signal appearing across the anode load, whose varying amplitude is dependent on the gas density encountered in the shock tube. For common β -emitters, where $E_{\max}$ is usually of the order of mev, the voltage signal is of sufficient magnitude to be passed directly to a high-speed cathode-ray oscilloscope. To obtain the statistical accuracy of 5% required, we must ensure that the integrating time constant of the load circuit is such that the voltage waveform is shaped by the circuit and not by either the scintillator decay characteristic time or the photomultiplier transit time. Clearly, as these are 2 ns and 30 ns respectively, no trouble will arise.

6. Specifications for the β -source

In estimating the amount of radioactive material required, we must distinguish between the integrated number of counts recorded per second dB/dt and the number of disintegrations per second dN/dt . Their relationship will be governed by

- (i) the self absorption in the source;
- (ii) the effect of back-scattering by the mounting of the source;
- (iii) the absorption occurring in the window shielding of the phosphor; and
- (iv) the geometrical efficiency of the phosphor G .

Considering each in turn, it is obvious that if we are considering weak β -particles with energies less than 1 mev, then some of the β -particles emerging from the back of the source will be totally absorbed in the volume of the source and so will contribute nothing to the source activity. Minimizing self-absorption lies with the supplier of the radioactive source; much can be done by careful consideration of the geometry. We shall see that the source strength actually required is readily obtainable commercially.

Back-scattering by the source can be controlled. The greater the density of the base or backing material, the greater is the back-scattering. Hence, mounting the sample on thin plastic film such as polystyrene of $2-3 \text{ mg}/\text{cm}^2$ thickness can reduce the back-scattering to about 1% (see Etherington 1958).

It is necessary to screen the phosphor from the hot gas flow behind the shock wave because experiments show that the gas can become visibly self-luminous. Clearly this radiation must not fall on the phosphor, resulting in the detector requiring screening by a light-tight window. Franzen and Schellenberg (1956) have considered this problem and shown that aluminium is superior to all other metals over the entire visible spectrum, on a basis of maximum light absorption per unit thickness; furthermore, it has the advantage of low density and therefore low stopping power for the weak β -rays used in the densitometer. The absorption in the window will be governed by the equation

$$\frac{I_D}{I_w} = \exp(-\mu t_w) = \exp\left(-\frac{\mu}{\rho} D \frac{\rho t_w}{D}\right).$$

we define $\epsilon_w = \rho t_w/D =$ window thickness in terms of the maximum range D of the β -particles (where t_w is the thickness of the window in centimetres) then this equation becomes

$$\frac{I_D}{I_w} = \exp\left(-\frac{\mu}{\rho} D \epsilon_w\right). \quad (5)$$

The range D (maximum distance) of β -particles in any medium is given by Katz and Penfold (1952) as

$$D = 412 E_{\max}^n \quad (6)$$

where

$$n = 1.265 - 0.0954 \ln E_{\max}.$$

where D is in mg/cm², $E_{\max}$ is in MeV and the equation is valid in the range 0.01 to 3 MeV.

For weak shock waves, for example less than Mach 8 moving into very low density air, with p_1 less than 1 cm of mercury at 300° K, such a detector window should not be necessary.

7. Numerical example using ³⁵S

The choice of a suitable radioactive source is dictated largely by the shock tube experiment and consequently the density ratios to be expected for a given downstream pressure and shock Mach number. A list of pure β -emitters is given by Allen, Millett and Smith (1959); a selection of suitable sources is given in Table 2.

Table 2. Properties of commercially available pure β -emitters

Element	³ H	⁶³ Ni	³⁵ S	¹⁴⁷ Pm	⁴⁵ Ca	¹⁸⁵ W	⁹⁰ Sr
$E_{\max}$ (MeV)	0.018	0.067	0.167	0.22	0.25	0.43	0.54
Half-life	12.26 y	125 y	87.2 d	2.6 y	153 d	73 d	28 y
Saturation specific activity (mc/g)	—	21	10.3	3.4	0.57	5.7	—
				of Nd			

Consider ³⁵S with a half-life of 87.2 days and $E_{\max} = 0.167$ MeV. For this radio element

$$\mu/\rho = 131 \text{ cm}^2/\text{g} \text{ from Eqn (2)}$$

$$D = 31.5 \times 10^{-3} \text{ g/cm}^2 \text{ from Eqn (6).}$$

Figure 4 shows a plot of Eqn (5) for ³⁵S.

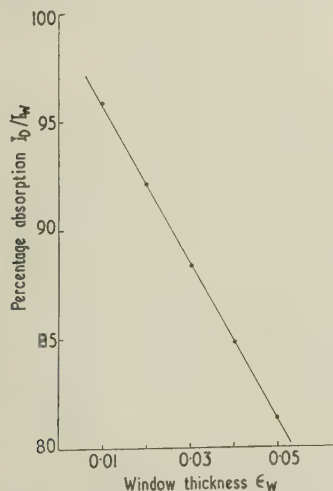


Fig. 4. Percentage absorption of β -ray intensity in scintillator window versus window thickness expressed as a fraction of maximum β -ray range.

Equation (4) gives, for the voltage appearing across the anode load,

$$V = 0.38G \text{ v.}$$

We shall show below that G is not less than about 0.01, so that a satisfactory signal is produced across the photo-multiplier load for transmission to a C.R.O.

If we stipulate that 95% of the radiation incident on to the detector window is transmitted to the underlying phosphor then, using Fig. 4, we find

$$\rho_{Al} t_w \leq 164 \mu\text{g/cm}^2.$$

We must also ensure that the dominant absorption occurs in the gas and not in the detector window. Reference to Figs 1 and 2 shows that ³⁵S is suitable for a range of pressure p_1 of 1 cm and above. At this pressure of 1 cm we have $\rho_2 t = 417 \mu\text{g/cm}^2$. Clearly the absorption occurs mainly in the gas. The preparation of thin light-tight aluminium windows for scintillation counters is discussed by Franzen and Schellenberg (1956), who give a technique for preparing such thin films with a thickness of 50 $\mu\text{g/cm}^2$ or less.

The quantity of ³⁵S required is readily obtained. We have

$$\frac{dN}{dt} = \frac{1}{G} \frac{dB}{dt}.$$

If the radioactive source were a point source and if the detector was moulded polystyrene, such that its shape was

a strip flush with the inner wall of the cylindrical shock tube of length $2h$ (measured along the axis of the tube) subtending an angle of 2α at the centre of the tube, then analysis shows that

$$G = \frac{4h}{(h^2 + t^2)^{1/2}} \int_0^{\alpha/2} \frac{d\chi}{\left\{1 - \left(\frac{t^2}{h^2 + t^2}\right) \sin^2 \chi\right\}^{1/2}} \\ = \frac{4h}{(h^2 + t^2)^{1/2}} F\left\{\left(\frac{t^2}{h^2 + t^2}\right)^{1/2}, \frac{\alpha}{2}\right\}$$

where the function F is a tabulated incomplete elliptic integral of the first kind. Representative values are

$$h = 0.1 \text{ cm}, \quad t = 4 \text{ cm}, \quad \alpha = 60^\circ, \quad \text{giving } G = 0.055.$$

However, the source will not be a point source but rather distributed in the same manner as the detector; clearly G will be considerably increased above this value of 0.055. We shall, however, use $G = 0.055$. As $dB/dt = 2 \times 10^8$, we obtain $dN/dt = 3.64 \times 10^9$ disintegrations per second, which is about 100 millicuries. Such a source could be produced in a nuclear reactor by irradiation of a suitable target material, e.g. KCl in the reaction $^{35}\text{Cl}(n, p)^{35}\text{S}$. The equation governing the rise of specific activity of an irradiated sample is an exponential function with a saturation value of S_{sat} , which is achieved when the irradiation time exceeds about four times the decay half-life. The total activity of the sample is obtained by multiplying S_{sat} by the pile factor, mass

of the sample and fraction of the target element in the sample—in this case 48%. Table 2 includes values of S_{sat} for a pile factor of unity, i.e. 10^{11} neutrons per square centimetre per second. The *Radioactive Chemicals* handbook (United Kingdom Atomic Energy Authority 1960) lists radio chemical compounds of ^{35}S commercially available—the 100 millicuries required could be obtained at reasonable cost. As remarked above, as the source is not a point source the value of G that we have used is an underestimate, so that the number of millicuries we would actually require would be less than 100.

Any uncertainties or inaccuracies in the theory could readily be eliminated because the densitometer could be calibrated statically, i.e. by merely adjusting the pressure p_1 through a series of values and noting the absorption occurring.

This type of densitometer is not restricted to β -rays. There are advantages to be gained by using γ -rays from pure γ -emitters and also the commoner β - γ activity from radiochemicals. It is proposed to discuss the merits of the various radioactive emanations in a later paper.

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Construction and operation of a simple flame-ionization detector for gas chromatography

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MS. received 10th August 1961

Abstract

The construction of a cheap and simple gas chromatograph incorporating a flame-ionization detector is described.

1. Introduction

SINCE it was first used by James and Martin (1952), nine years of rapid development have firmly established gas chromatography as a very versatile technique for solving complex mixtures of organic compounds into their components. One of the more important advances has been the construction of detectors whose sensitivity is 2 or 3 orders more than those originally used (Scott 1957, McWilliam and Newar 1958, Harley *et al.* 1958, Lovelock 1958, Thompson 1959). This has led to the use of very small samples (less than 1 μ l) and indirectly to the development of very high efficiency columns (Golay 1958). With the increased complexity of apparatus, however, and the consequent need for specialized skills and equipment for its construction, it is possible that smaller laboratories may be deterred from investigating the possibility of applying this technique, particularly in its more sensitive forms, to their own field of work. The equipment described in this note may be of interest to laboratories such as these, because it is easily constructed by anyone with a minimum of glass-blowing technique and a knowledge of simple electrical components. The cost of materials is approximately £50 (excluding a recorder), and its sensitivity and stability is comparable with that of a commercial high sensitivity chromatograph. Another version of a cheap and simple gas chromatograph, embodying a flame-ionization detector, but of different design, is described by Smith (1960).

2. Apparatus

2.1. Flame-ionization detector

The dimensions of this are not critical. The body is made from Pyrex tubing whilst the jet itself is made from a 2 in. length of 20 or 22 gauge hypodermic tubing soldered to the end of a hypodermic needle. The latter is sealed into the body with Araldite (Fig. 1).

Electrical connection to the needle (grid) is made through a coiled length of 24 gauge platinum wire brazed to it. The positive terminal, which is about 7 mm above the tip of the needle, is 20 gauge platinum wire. Both wires are connected to the electrical circuit through screened coaxial cables, the screening being earthed.

The detector is connected to the column through the joint shown in Fig. 2, in which the tip of an Agla micrometer ringe barrel has been fused to a spherical joint (ball) with a small side arm. Except when the flame, which is about 0.3 mm high and almost invisible, is being lit, the detector

is covered with an inverted small glass or metal trough with a $\frac{1}{8}$ in. central hole, to exclude dust. About 36 litres per hour of air is blown through A, to support combustion and also to keep out dust particles from the flame.

The air is supplied by a 1/400 h.p. pump (Charles Austen Pumps Ltd., type DYMK 2) connected to a 20 litre reservoir, and passes through a fine filter paper before entering the detector.

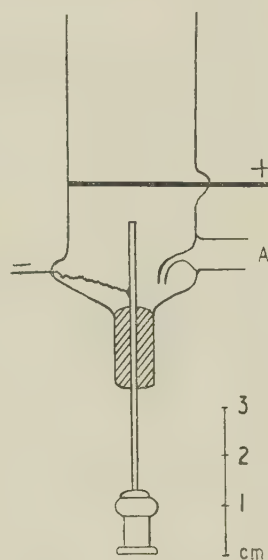


Fig. 1. Glass detector.

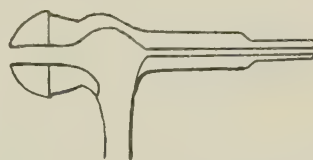


Fig. 2. Mixing chamber.

2.2. Column

This is made from 4–5 mm Pyrex tubing bent into a succession of V-shapes for compactness. At the exit is a spherical joint (socket), which eliminates rigidity and the possibility of breakage when connecting a new column to the detector. The sample is introduced by microdipper through a B10 ground glass socket at the other end, whilst below this socket is a side arm through which the nitrogen enters the column, via an on-off tap.

2.3. Heating bath

The column is immersed in a suitable liquid contained in a 5 litre beaker lagged with asbestos cord. The beaker also contains a stirrer, a 500 watt bar heater and a bi-metal thermostat connected through a hotwire vacuum switch to a Variac transformer, which is used to regulate the heater current and consequently the bath temperature. More stringent thermostatic control is unnecessary as flame-ionization detectors are unaffected by small variations in column temperature.

2.4. Carrier gas

Nitrogen is used as the carrier gas through the column, the flow rate being about 3 litres per hour. The flow is stabilized by means of two ballast vessels, of about 20 litres and 2 litres capacity, separated by a needle valve (Edwards High Vacuum Co. Ltd., type OS.IC).

The nitrogen (from a cylinder throttled to about 10 lb/in² pressure) passes into the large tank and then via the needle valve to the second tank. The flow issuing from the latter is constant and can easily be regulated by the needle valve. Either a rotameter or a soap film flowmeter can be used to measure the flow at the outlet of the column and to calibrate the needle valve setting in terms of flow rate for a particular column.

Hydrogen for combustion is fed from a cylinder into the side arm B of the connecting joint; its flow rate (which needs to be constant to avoid fluctuations in the base line) is about 5 litres per hour. Under these conditions, when the nitrogen flow is re-started after introduction of a sample, the flame remains slight.

2.5. Electrical circuit

The basis of the flame-ionization detector is that the electrical resistance of the flame is very much affected by traces of organic compounds, although the precise mechanism is rather involved. Consequently, if a constant voltage (in this case, 250 v d.c.) is applied between the jet and the platinum wire, the current flowing alters when a compound

is eluted from the column. A simple cathode follower circuit (Fig. 3) is used to convert the change produced into

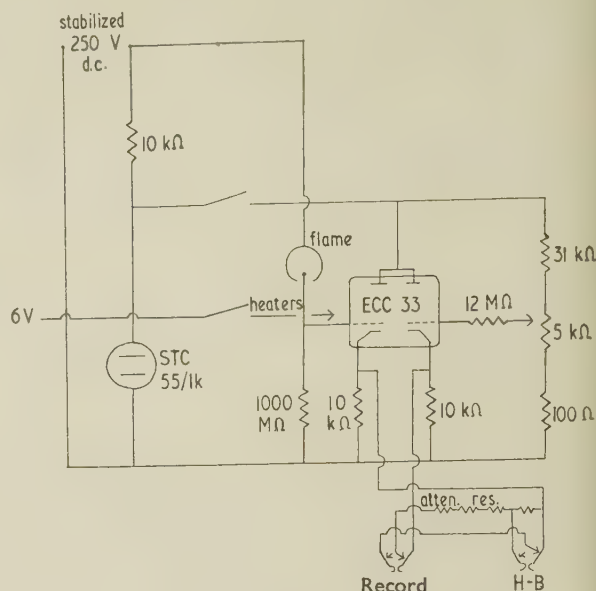


Fig. 3. Cathode follower circuit.

a form suitable for feeding into a recorder. We have used both Honeywell-Brown millivolt potentiometric recorders and also the cheaper Record recorders (0.3 mA, 1500 ohm) and the circuit (which is cheap and easy to construct) is designed for this dual purpose.

To eliminate base-line disturbances caused by surges in the thermostat circuit, 10⁴ pF capacitors are connected across both load and control terminals of the Vacuum Switch. The valve STC/1K is a neon stabilizer, supplying 55 v to the anode of the ECC 33.

Comparison of sensitivity of laboratory flame-ionization detector (A) with commercial radioactive source-ionization instrument (B)

	Volume (μl)	Signal (mv)		Sensitivity (mV ml/mg)	
		A	B	A	B
Ethanol (1% v/v in ether)	0.1	1.60	1.45	140 × 10 ³	82 × 10 ³
		1.55	1.30		
		1.25	1.30		
Tetrahydrofuran (1% v/v in ether)	0.1	3.50	2.95	290 × 10 ³	74 × 10 ³
		3.05	3.25		
		2.65	2.75		
		3.10	2.90		
Carbon tetrachloride (1% v/v in ether)	0.1	3.55	1.90	50 × 10 ³	20 × 10 ³
		2.30	2.50		
		4.20	2.05		
		3.40	1.35		
Methyl formate				140 × 10 ³	130 × 10 ³
Methyl acetate				100 × 10 ³	70 × 10 ³
Benzene				280 × 10 ³	150 × 10 ³
Acetone (5% v/v in ether)				240 × 10 ³	80 × 10 ³
Nitromethane (5% v/v in ether)				72 × 10 ³	58 × 10 ³

Sensitivity has been expressed as mv ml/mg for both instruments for ease of comparison. The more correct unit of $\mu\text{A mg}^{-1}$ (Ongkiehong 1960) for the flame-ionization detector gives values of about 0.5×10^6 . A signal of 5 mv (i.e. 50% full scale deflection) on the potentiometric recorder corresponded to one of about 70 μA (i.e. 23% full scale deflection) on the record recorder.

3. Sensitivity

The Table gives a direct comparison of the sensitivity of a laboratory-made unit operated at 50° C with that of a commercial radioactive source/ionization chromatograph operated at maximum voltage in the ionization cell. As will be seen, sensitivities are of the same order of magnitude. Noise level on the laboratory instrument is somewhat higher (between 0.05 and 0.1 mv on the potentiometric order) but not nearly sufficient to cause serious interference; base line drift is not noticeable. On the Record order, noise was not detected. Operating at 150° C, the Record recorder was found to be more suitable, as there was considerable 'noise' on the potentiometric recorder.

Acknowledgments

I am grateful to Mr. A. Heywood (Division Analytical Department, Imperial Chemical Industries Ltd., Dyestuffs Division), who developed the first model using a glass flame-ionization detector of this type, a one valve cathode follower

and Record recorder, and who provided much useful information on the construction and the operation of his type of apparatus.

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Notes and comments

Conference on 'The Ionosphere'

The Institute of Physics and The Physical Society announces that it is arranging a conference on 'The Ionosphere' to take place in London from 2nd-6th July, 1962. It is intended as a working conference and no social activities are planned. The subjects to be covered and the opening speakers are: Ionospheric Constitution and Ionizing Radiations by Dr. Friedman of the U.S. Naval Research Laboratory, Washington; Geomagnetism and the Ionosphere by Dr. O. Hines of the Defence Research Telecommunications Establishment, Ottawa; Irregularities in the Ionosphere by J. B. H. Briggs of the Cavendish Laboratory, Cambridge; Mathematics of Wave Propagation through the Ionosphere by Professor H. G. Booker of Cornell University. Each of these principal sessions will be opened by the named speaker and offers of other contributions are invited. These should be accompanied by an abstract of 100-150 words each and be sent to the Chairman of the Organizing Committee, Mr. J. A. Ratcliffe, at the Radio Research Station, Ditton Park, Slough, Bucks, before 1st March next. The final scripts will be required by 1st June, 1962, and it is hoped that publication of the proceedings of the conference will take place very soon after the close of the conference. The official languages of the conference will be English and French but whenever possible papers and abstracts should be presented in English. The organizers are not proposing to make any special arrangements for accommodation for those attending the conference. Those wishing to do so are strongly advised to book hotel accommodation in London very early in the New Year. Foreign visitors should be assisted by the London Hotels Information Service, Brook Street, London, W.1.

Further particulars will be available at the end of March from the Administration Assistant, The Institute of Physics and The Physical Society, 47 Belgrave Square, London, S.W.1.

Notes on the British Iron and Steel Association Open Days

The British Iron and Steel Association has compiled a set of notes on the exhibits which were displayed at their open days at Sheffield in June, for the information both of those who were able to attend the open days and to others interested in the Association's work.

Copies of these notes are available, free of charge, from The Information Officer, Development and Information Services, British Iron and Steel Association, 11 Park Lane, London, W.1.

Diamonds in Industry

We have received a copy of the booklet *Diamonds in Industry* which has been published by the Industrial Diamond Information Bureau. It has been prepared for students and engineers and contains information under the headings of The hardness of diamond, Gem polishing, Grinding wheels, Glass working, Dressing and truing, Honing and lapping, Diamond saws, Diamonds for drilling, Diamonds for lathe tools and wire drawing dies, Non-cutting uses of diamond and New applications.

Copies may be obtained, free of charge, from the Industrial Diamond Information Bureau, 2 Charterhouse Street, London, E.C.1.

Tripping a 1 MV single-stage impulse generator

by T. E. BROADBENT, M.Sc., Ph.D., A.M.I.E.E., and R. COOPER, M.Sc., Ph.D., A.M.I.E.E., Electrical Engineering Department, University of Manchester, Manchester 13

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Abstract

A method is described of tripping a single-stage 1 MV impulse generator, using a beam of light and no direct electrical connection between the tripping circuit and the impulse generator. The method facilitates synchronization of the recording cathode-ray oscilloscope time sweep with the output impulse.

Introduction

THE high-voltage generator in the Electrical Engineering Department of Manchester University is a Cockcroft-Walton voltage doubler giving output voltage of either polarity up to 1 MV. The output capacitor consists of four $0.05 \mu\text{F}$ units connected in series and mounted, one on top of another, in a vertical stack. The base of this stack is insulated to withstand 250 kV to ground. In certain investigations impulse voltages are required. They can be obtained by discharging the above output capacitor into a suitable pulse-forming network via a spark-gap formed between two horizontally mounted, 1 m diameter spheres. The breakdown of this spark-gap can be initiated in a number of ways (Hardy and Broadbent 1955). The method described has advantages if the output impulse must be synchronized with a number of other events; also it avoids the expense and recording error of a delay cable.

A sphere-gap may break down at a voltage considerably below the normal direct breakdown voltage V_{dc} if dust particles are present. An essential requirement of an impulse generator tripping system is that this shall not occur; its success in meeting this requirement can be measured by its 'working range'. This term is used here to denote the difference between the normal (i.e. dust-free) direct breakdown voltage of a gap V_{dc} and the least charging voltage at which breakdown of the gap is ensured each time the tripping process is initiated V_{min} . The difference is expressed as a percentage of V_{dc} . Clearly the greater the working range, the less likely is inadvertent operation.

Method

Gaps of up to 60 cm in length between 75 cm diameter spheres can be triggered with 10 kV impulses, using the trigatron method (Broadbent 1960). This can be applied to the tripping of a single-stage impulse generator provided both ends of the output capacitor are insulated to the same level from ground. In such a case one of the spheres can be permanently at ground potential and no problems arise with insulation of the trigger impulse generator circuit. The above provision does not apply in our laboratory but the trigatron method nevertheless has been used successfully with voltages up to about 1 MV.

The method is illustrated in Fig. 1. A push-button switch

triggers both the oscillograph time base and a xenon flash tube that gives a light pulse of a few microseconds duration. The high-voltage sphere of the main spark-gap (g) contains

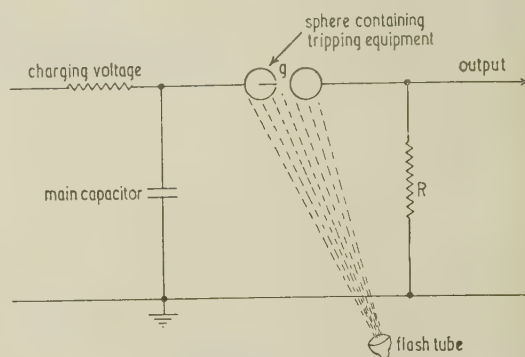


Fig. 1. New tripping system.

the triggering equipment, consisting of a photocell, amplifier and 10 kV pulse generating circuit. Light from the flash tube illuminates the sphere and falls on to the cathode of the photocell and so activates the system. The tripping sequence is illustrated in Fig. 2.

The photocell, amplifier and pulse generating circuits are operated from three 120 V h.t. batteries connected in series (for h.t. supplies) and a 6 V car battery (for filaments). The e.h.t. supplies for the triggering circuits are obtained from a 10 kV r.f. power supply, fed from the same batteries. The switch for the equipment is mounted inside the sphere and is operated from ground by a $\frac{1}{8}$ in. diameter nylon cord.

The combination of photocell and pulse amplifier proved to be both sensitive and selective. Because of the high sensitivity it was not necessary to accurately focus the transient light beam on to the photocell. On the other hand, relatively slow variations in background illumination caused, for example, by switching on and off the tungsten filament lamps used to illuminate the laboratory, had no effect because of the amplifier characteristics.

The overall time lag between applying a steep-fronted pulse to the amplifier input and breakdown of the trigatron annular gap was almost constant and less than $0.2 \mu\text{s}$. The mean time lag between the start of the time base and breakdown of the trigger rod of the main trigatron gap (g) was $1.3 \mu\text{s}$ in 200 successive tests. The scatter recorded was from $1.2 \mu\text{s}$ to $1.5 \mu\text{s}$. The time lags of about $1.3 \mu\text{s}$ were mainly due to the time delay between triggering the flash tube and the appearance of light output, but part of the lag was due to the circuits inside the sphere. Working range curves obtained for the circuit of Fig. 1 are shown in Fig. 3.

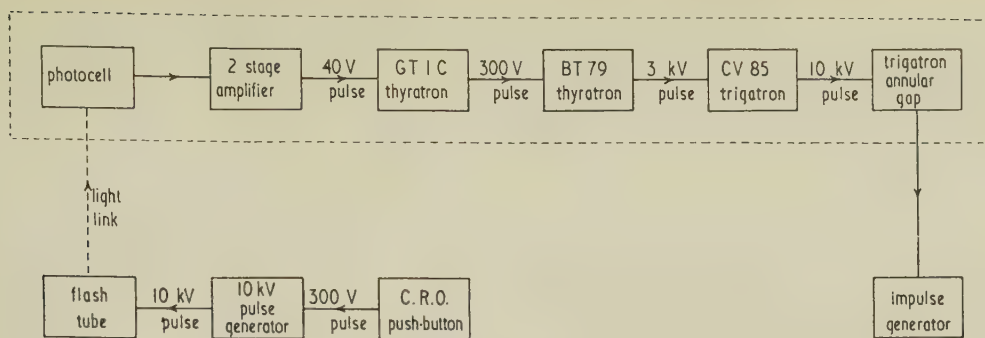


Fig. 2. Tripping sequence in method of Fig. 1.

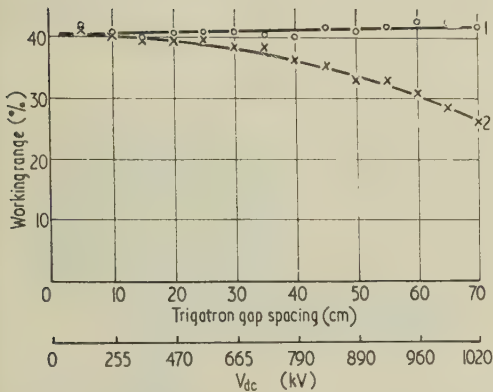


Fig. 3. Working range curves for method of Fig. 1.

Curve 1, positive charging voltage; curve 2, negative charging voltage.

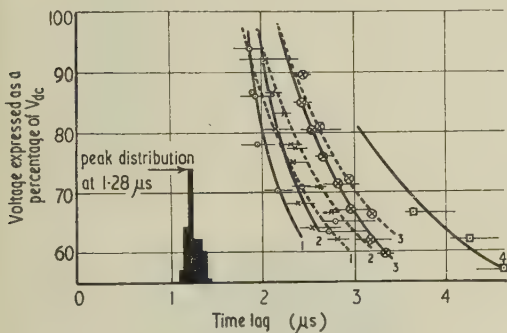


Fig. 4. Voltage/time-lag curves for method of Fig. 1.

— positive charging voltage; - - - - negative charging voltage.

Curve 1, 10 cm gap ($V_{dc} = 255$ kv); curve 2, 30 cm gap ($V_{dc} = 665$ kv); curve 3, 50 cm gap ($V_{dc} = 885$ kv); curve 4, 80 cm gap ($V_{dc} = 1060$ kv) (pos. only).

Horizontal lines through points represent scatter between maximum and minimum time lags. Histogram shows distribution of time delay between initiation of triggering and breakdown of trigatron annular gap.

and curves relating the time lag between the start of the time base and the breakdown of the trigatron main gap (g) are

given in Fig. 4. Since the time delay between the start of the time base and the breakdown of the trigatron annular gap is approximately constant (as quoted above), the variable part of the total time delay is the time elapsing between the trigger rod breakdown and the breakdown of the main gap. This depends on the voltage between the trigatron main electrodes, trigatron gap spacing, and polarity (Broadbent 1957).

Discussion

The method may appear superficially similar to a previous system (Husbands and Higham 1951) in which the breakdown voltage of a sphere-gap is reduced by direct illumination from a second spark-gap. The reduction depends on the intensity of illumination, which depends on the energy in the illuminating spark and its distance from the gap (Meek 1942). This former method, however, suffers from the defect of a very small working range. For example, in an experiment with a gap of 35 cm between 75 cm diameter aluminium spheres we obtained a working range of less than 2%. The triggering spark was mounted 1.75 m from the axis of the main spark and equidistant from the two spheres. The energy of the undamped triggering discharge was 10^3 joules.

With the new method adequate time exists in which to initiate the C.R.O. time sweep. The time delay is due mainly, but not entirely, to the delay in the firing of the trigatron trigger spark. This delay is approximately constant and is indicated on Fig. 4. The time to breakdown of the main gap decreases as the applied voltage is increased but the effect becomes smaller at the higher voltages and the time lag curves approach a constant value. This, presumably, is the formative time of the spark. Little appears to be known about the formative time lag in gaps comparable with those used in this investigation.

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Diamond knife trough for the ultra microtome

by R. PHILLIPS* and J. H. LUCAS, Aeon Laboratories, Egham, Surrey

MS. received 4th July 1961

Abstract. A diamond knife trough is described which does not rely on grease, wax or plastic seals to prevent cutting fluid leakage. This allows organic solvents such as xylol to be used as cutting fluid, without contaminating the knife and producing leaks. This type of cutting fluid is required for easily oxidizable metals such as magnesium. The new knife trough also permits the mounted knife to be cleaned in organic solvents without damage to the trough, and without impairing the seal.

Introduction

Diamond knives for ultra microtomes are commonly supplied in a metal mount, as shown in Fig. 1. These knives have to



Fig. 1. Diamond ultra microtome knife in its brass mount.

be mounted in troughs which are capable of being gripped by the microtome knife holder, and of containing a liquid whose meniscus is adjusted to be flat at the diamond edge. Commercial troughs rely on a wax or silicon grease to prevent leaks. This is satisfactory for the distilled water and dilute aqueous solutions of solvents usually employed in the trough. Special applications, however, necessitate the use of other liquids, in the trough, e.g. easily oxidized metals such as magnesium and uranium are cut over xylol, and under these conditions the seals break down and commercial troughs leak rapidly. Furthermore, knives in troughs which are not dependent on grease or wax seals may be cleaned by soaking in solvents, which is one of the least damaging and most effective methods of cleaning available.

Apart from it being undesirable permanently to commit a trough to one knife, it is found that even cured Araldite is unsatisfactory as a sealing material when employed in constant contact with xylol. It was therefore decided to design a knife trough which would seal by contact only. For this type of seal to have any chance of success, the

surfaces of the brass knife-mounts must be accurately plane and square. The provision of this type of mount is entirely in the hands of the diamond knife manufacturer, and it is hoped that attention will be paid to this point.

The material chosen for the knife trough was duraluminium because it combines strength (important for long life of screw threads and accurate clamping of the trough in the microtome), with a low rate of corrosion, yet it has the ability to deform very slightly to match a fairly accurately mating surface.

Design

The trough was milled to a maximum depth of 0.3 in. by means of a 0.3 in. diameter end-mill with an end radius of 0.1 in. This produced an internal form with no sharp angles, which was easy to clean. The dimensions of the liquid surface when the trough is filled are approximately

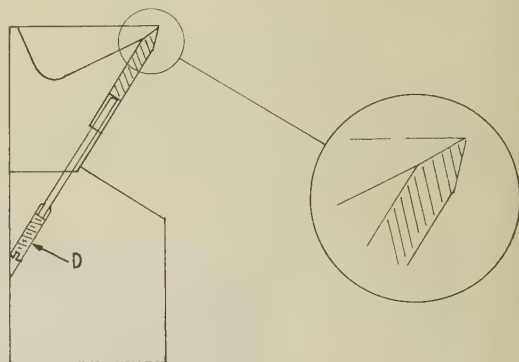


Fig. 2. Cross section of diamond knife trough.

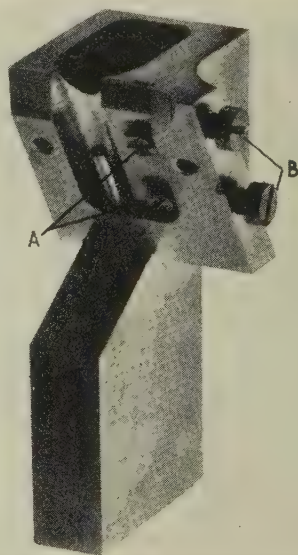


Fig. 3. Photograph of front view of the knife trough.

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in. by 0.3 in. Thus, a volume of fluid is employed which is easily handled, but which presents a low surface area to the trough and atmosphere. The latter tend to be sources of contamination of the cutting liquid, and therefore sections and support films.

The surface of the trough is arranged to merge into the face of the diamond knife as smoothly as possible (Fig. 2). The knife is clamped into the milled recess in the back of the trough by means of a jib strip retained by screws A, and is driven against the side of the knife mount by the screws B (Fig. 3). The knife height may be altered by pre-setting the screw D (Fig. 2), which is accessible from the back of the trough. The trough is provided with a tongue of suitable external form for the particular microtome for which it is intended.

When a new knife is to be mounted in the trough, a bridge is firmly screwed on to the trough (Fig. 4), the knife slid into position and lightly gripped by screw C (Fig. 4). The knife

is set to the required height by the screw D. The jib strip is also gripped by its retaining screws A. Next, the screw C is fully tightened, and then the screws B are alternately tightened, to ensure good contact between the back and sides of the knife mount. When this has been achieved, the jib strip screws A are checked for tightness, and the bridge is removed.

Conclusions

This type of trough has been in use for six months, and has generally proved superior to the available alternatives. Where trouble has been experienced, it has been due to:

- (a) Lack of planeness or squareness of the knife mount.
- (b) A gap between the actual diamond and the brass mount near the knife edge.
- (c) The edge of the brass mount not being in line with the knife edge, or
- (d) Dirt on the mating faces of the knife mount and trough.

In all cases except the last, the microtomist has to rely on the diamond knife manufacturers to avoid the source of difficulty. A small elaboration in design could, however, probably overcome the difficulties arising in the geometry of the knife mount. It is suggested that a groove be machined in the faces of the trough and jib strip, which mate with the

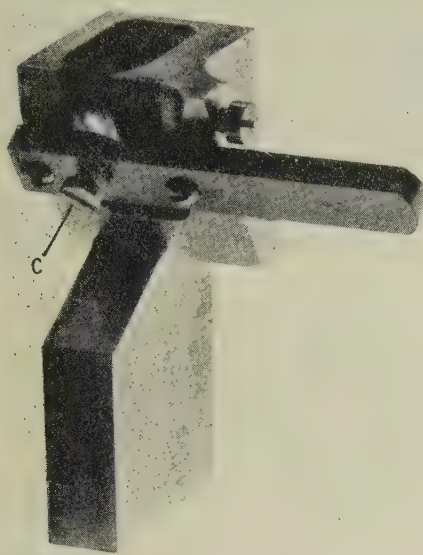


Fig. 4. Knife trough with knife-mounting-bridge in position.

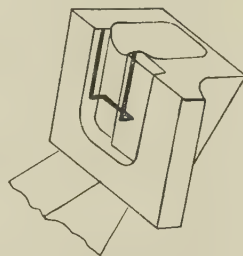


Fig. 5. Groove for suggested aluminium or indium wire seal.

knife mount as shown in Fig. 5, and that indium or aluminium wire be placed in this groove similar to its use in modern vacuum technology.

Two megacycle ultrasonic interferometer

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M.S. received 11th July 1961

The instrument to be described has been used for several years in these laboratories for measuring sound velocities in liquids over the temperature range -100° to $+70^{\circ}$ C. The general features of the design and the method of operation are standard (Bergmann 1938), but the details of the design make it easy to construct and to use. It is accurate to better than $\frac{1}{2}\%$ when the absorption of the liquid is low enough to allow 20 or more 'beats' to be identified.

The cell (Fig. 1) consists of a $\frac{7}{8}$ in. bore, stainless steel tube A closed at the bottom end by a 2 Mc/s, 1 in. diameter, X-cut

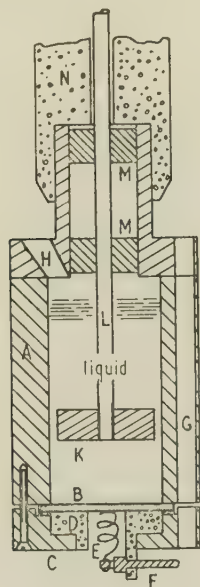


Fig. 1.

quartz crystal B. The end of the tube is carefully machined so that the gold-plated, polished surface of the crystal makes a liquid-tight joint and electrical connection with it. A 0.003 in. thick polythene gasket separates the bottom surface of the crystal from the clamping ring C. The Bakelite insulator D does not press on the crystal but prevents the phosphor-bronze spring E from touching C and carries the brass terminal F, to which the spring is soldered. The other end of the terminal is soldered to the centre conductor of a coaxial cable which is led down the hole G. The cell is filled through the entrance H and the temperature of the liquid is measured by a thermistor which dips down into the liquid through the same entrance.

The bottom surface of the non-rotating, stainless steel reflector K is machined *in situ* together with the bottom surface of the tube A. This ensures the parallelism of the top surface of the crystal and the bottom surface of the reflector. The reflector is $\frac{3}{4}$ in. diameter and $\frac{1}{4}$ in. thick. The $\frac{1}{8}$ in. diameter stainless steel rod L which carries the reflector, is guided by the two bushes M. The cell is supported by a thick Bakelite tube N, 10 in. long, which acts as a thermal insulator. The upper end of the rod L is prevented from rotating by a key-way (not shown) and vertical movement of the rod is measured by a dial gauge which rests

on a small platform screwed to the top end of the rod. A large nut running on a fine screw, through which the rod passes, is used to move the rod up and down.

The cell is surrounded by a close-fitting brass container, suspended by a light Bakelite tube, so that the combination can be lowered into a constant temperature bath or Dewar flask.

The crystal is driven at 2 Mc/s via the coaxial cable by a conventional push-pull oscillator with an over-coupled output coupling coil. The coaxial cable should be short because its capacity shunts the impedance of the crystal. Over-coupling of the oscillator to the cable and crystal ensures that small changes in crystal impedance will alter the oscillator frequency. The change in frequency is measured by the audio beat between the oscillator and the 2 Mc/s crystal oscillator in a BC221 frequency meter (U.S. Surplus Equipment).

The instrument is set up by adjusting the oscillator to give a zero beat at one of the positions of the reflector corresponding to standing wave conditions in the liquid between the crystal and reflector. If the crystal-reflector separation at zero beat differs from the critical standing wave separation, pairs of zero-beat positions will be found on either side of the true standing wave separation (Fig. 2). Starting with the

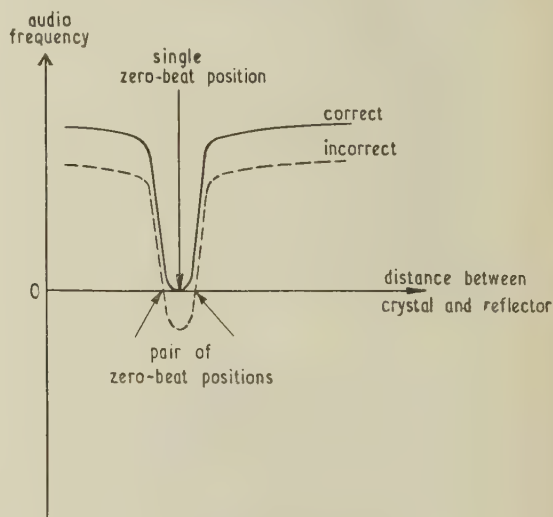


Fig. 2.

reflector only about one millimetre from the crystal, the positions of at least 20 successive zero beats are measured on the dial gauge. The mean distance between successive standing wave positions is equal to one half sound wavelength, i.e. $\lambda/2$, from which the sound velocity c is calculated to be $c = \lambda f$. The frequency f equals 2 Mc/s to the accuracy of the crystal oscillator.

Greater accuracy of measurement could probably be achieved by better arrangements for temperature control and by higher precision in the construction of the mechanical parts.

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Magnetically operated shutters for use in vacuum systems

by F. S. FEATES, Ph.D., B.Sc., A.R.I.C., Chemistry Division, Atomic Energy Research Establishment, Harwell, Didcot, Berks.
 MS. received 24th August 1961

Abstract. Two magnetically operated shutters which have proved reliable in high-vacuum systems are described. One allows selection of any of four apertures, the other is a simple ON-OFF device.

A nitric oxide filled ionization chamber similar to that designed by Comes and Schlag (1959) has been used to measure the radiation output from a high intensity vacuum ultra-violet source (Feates *et al.* 1960). The chamber carried a thium fluoride window and was mounted directly on to the source. A shutter was required to shield the window from the radiation except at the instant of measurement, for the transmission of LiF is reduced by excessive exposure to radiation. In addition, the flux range over which the ionization chamber was sensitive was limited, and a variable aperture shutter was desirable. As the position of the shutter was not visible when in use, great reliability of operation and location was essential.

Two devices have been constructed which permit the insertion of a shutter between the source and the chamber. To retain the high sensitivity of the chamber the units were made as short as possible so that the solid angle subtended to the chamber was not greatly reduced.

One shutter is illustrated in Fig. 1. It consisted of a strip

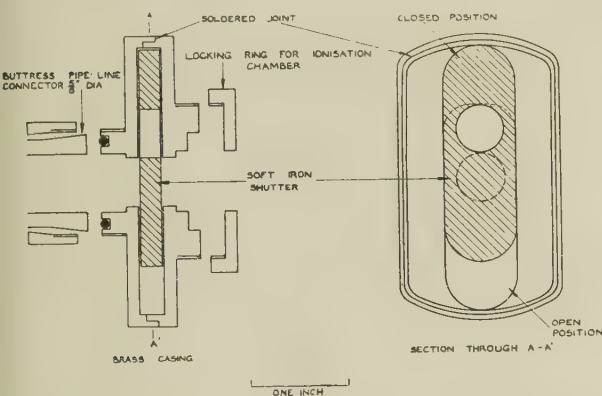


Fig. 1.

of soft iron drilled near one end and contained in an outer brass casing with O-ring grooves for attachment to the source and ionization chamber about an off-centre hole. The casing was constructed in two parts with a single hard soldered joint to reduce the possibility of leakage. The shutter was operated with an external magnet which drew the soft iron strip, either to align the holes or to interpose solid metal in the optical path. A 'click' could be heard when the soft iron had moved into its new position, serving to confirm satisfactory operation.

The second shutter (Fig. 2) was a development which made provision for three variable apertures to the chamber. The moving section was a $\frac{3}{16}$ in. thick $\times 1\frac{1}{2}$ in. diameter aluminium alloy disk mounted with polytetrafluorethylene (P.T.F.E.) bearings on a P.T.F.E. coated spindle. The disk was

pierced with three holes giving apertures in the ratio 1 : 2 : 4, with the largest hole $\frac{5}{8}$ in. diameter. Each of the smaller holes and the blank region were counterbored to balance the disk on the spindle. An $\frac{1}{8}$ in. diameter hole was drilled through

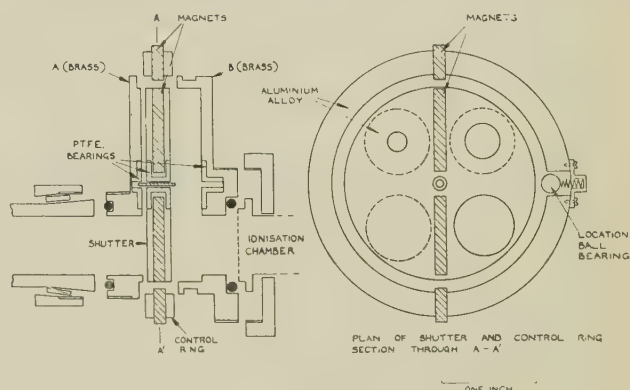


Fig. 2.

the thickness of the disk along a diameter between adjacent apertures and two $\frac{1}{8}$ in. $\times \frac{3}{8}$ in. long Ticonal cylindrical magnets were pressed into the holes so that opposite ends of the diameter had unlike polarities.

The disk was mounted in a two-section casing with 0.01 in. clearance at the sides and edges of the disk. The connections for source and ionization chamber were placed in line with the largest aperture in the disk. The outer rim of the casing was grooved and a control ring holding two small magnets was mounted on it. The magnets seated in the groove held the ring in position. Finally a spring-loaded $\frac{3}{16}$ in. diameter ball-bearing was inserted into the ring so that it engaged in one of four indentations in the bottom of the groove. The 'click' location which resulted enabled any aperture to be positioned readily. The outside of the casing and the ring were engraved to indicate which aperture had been selected.

In use the devices have proved to be very reliable and the location is precise. The range of apertures may be increased with suitable 'push-fit' inserts containing smaller holes which are introduced into the counterbored recesses with forceps through the radiation port. In addition, if filters or window materials are mounted on the disk it provides a very rapid method for the measurement of the transmission of the material against any reference.

Acknowledgment

The author is pleased to acknowledge the assistance of Mr. A. Boram in the construction of the shutters.

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Experimental microbarograph

by G. W. GARDINER, D.S.I.R. Radio Research Station, Ditton Park, Slough, Bucks.

MS. received 20th July 1961

Measurements of small fluctuations in barometric pressure are of interest in several applications, especially in the field of radio-meteorology. In studies of tropospheric wave propagation, for example, a method of recording the movement of relatively small-scale ridges or troughs over the transmission path is of particular value. This note describes an instrument which has been developed to meet this requirement. The pressure fluctuations of interest have a magnitude of 0.1–2 mb, with a period of five minutes to one or two hours.

Microbarograph instruments, such as that of Dines and Shaw (1905), use a thermally-lagged reference pressure chamber and are more suitable for investigations of short-period variations. Although the provision of a slow leak leads to a measure of thermal compensation, the effect of varying ambient temperature is troublesome when measuring slow changes of pressure.

In the instrument to be described, the free movement of an ordinary barograph aneroid unit is used to vary the capacitance in an oscillatory circuit. The construction of the pressure-operated capacitor is shown in Fig. 1. The total

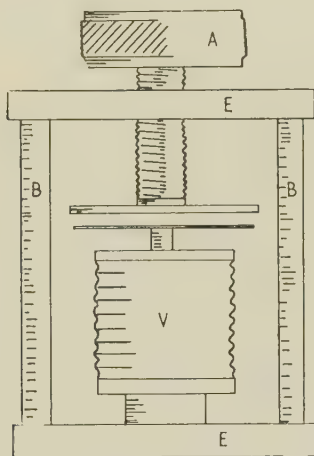


Fig. 1. Construction of aneroid capacitor. A, adjusting screw; B, brass pillar; E, ebonite; V, aneroid capsule.

capacity of the instrument may be varied by adjustment of the screw at A.

A satisfactory method of recording the capacity variations has been found to be a modification of the system due to Oliphant (1937). Energy from a crystal-controlled oscillator is fed into a tuned circuit L_2C (Fig. 2) which is nearly at resonance; the variations of the aneroid-controlled capacitor produce corresponding variations of current in L_2C . These fluctuations in turn produce changes in current in the detector circuit L_3 . The rectified voltage is amplified and displayed on a recording milliammeter.

It has been found useful in practice to 'back-off' some of the standing current in the circuit L_3 and this has been done by a potentiometer P connected to the oscillator h.t. supply, which is well stabilized. When a sensitive recording meter is used, no d.c. amplification is needed.

The system described above has been found satisfactory for the examination of pressure variations such as those associated with the passage of cumulonimbus cloud. An example of the type of record obtained is shown in Fig. 3.

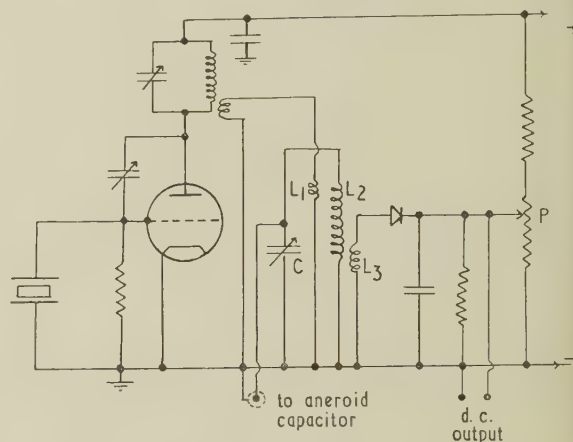


Fig. 2. Oscillatory circuit for microbarograph.

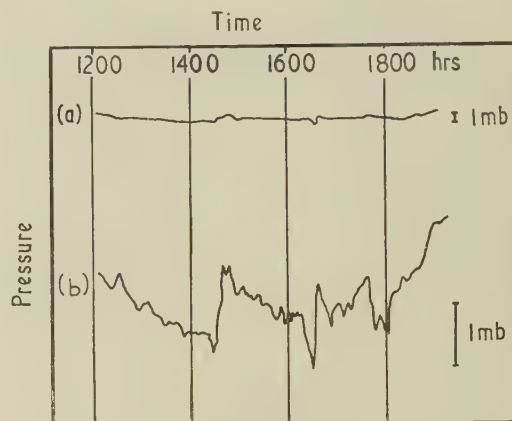


Fig. 3. Pressure fluctuations produced by passage of cumulonimbus cloud on 2nd May 1961. (a) M.O. pattern open scale barograph (time scale expanded to equal that of (b)). (b) Experimental microbarograph.

together with a normal open-scale barograph trace for the same period.

It has been found simplest to operate the device in a small box kept at constant temperature, although a construction using thermally compensating materials would render this unnecessary. The non-linearity of response has not proved inconvenient; but should a linear output be required, the plates of the capacitor could be replaced by coaxial cylinders. The limits of magnification are governed primarily by the stiffness and hysteresis of the aneroid capsule. No difficulty has been experienced for the requirement illustrated in the example, where a limit of 0.1 mb is all that is required.

The range of measurement is approximately ± 3.0 mb

out the ambient pressure, and the instrument is re-set by adjusting A in Fig. 1. Rapidly changing barometric situations (e.g. the approach of major depressions) may necessitate setting at intervals of a few hours, but in general the range chosen is such that adjustment is seldom required more than once a day.

In a more elaborate instrument, the thermal and mechanical stability could be improved, and automatic re-setting provided. However, the technique in its present form suffices to provide useful results in radio-meteorological applications.

The author is indebted to Mr. J. A. Lane for helpful discussion and comment during the preparation of this paper. The work described was carried out as part of the programme of the Radio Research Board. The paper is published by permission of the Director of Radio Research of the Department of Scientific and Industrial Research.

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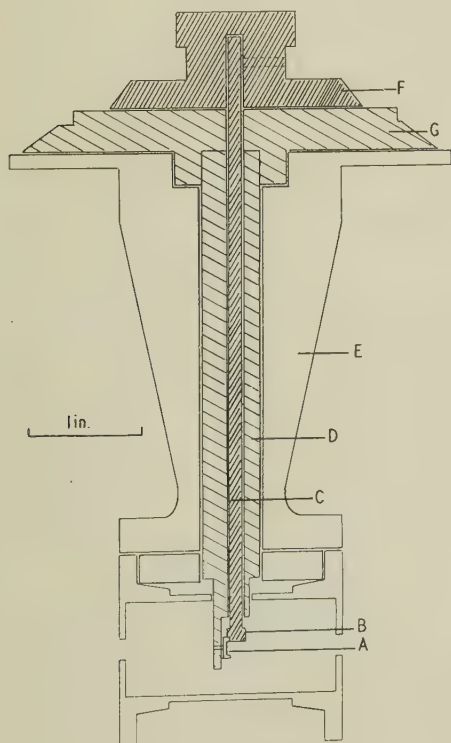
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Universal crystal mount for electron paramagnetic resonance measurements

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(Received 17th August 1961)

Interest in electron paramagnetic resonance of single crystals centres on the variation of the spectrum with the orientation of the crystal relative to the applied magnetic field. It is desirable to be able to set the crystal rapidly to any desired orientation with the minimum disturbance to the electromagnetic field inside the microwave cavity housing the crystal. This note describes an arrangement which we have used with an X band H_{012} transmission cavity. It provides for rotation of the crystal about two orthogonal axes and gives a reproducibility of 2° .



The crystal is mounted at the centre of a small Perspex crown gear wheel A which may be rotated about a horizontal axis by a nylon spur gear B on the vertical shaft C. These components are carried by the vertical shaft D which may be rotated in the rigid block E screwed to the cavity flanges. Large concentric aluminium scales F and G enable the positions of shafts C and D to be measured easily. It is particularly simple to change crystals since the whole assembly may be withdrawn from the block E, and the crown gear complete with crystal removed from its bearing and replaced by a new gear and crystal. The accurate initial positioning of the crystal is best done using a microscope.

The dimensions chosen are the result of a compromise. A large mounting will accommodate a large crystal but this will result in the 200 kc/s field modulation wires being in a region of strong microwave electric field, thereby reducing the Q of the cavity.

For the dimensions chosen the Q of the cavity is only marginally less than that of a cavity employing a smaller and less flexible mounting, and allowing a smaller separation between the modulation wires. However the maximum sized crystal which can be used is less than the optimum size for the maximum signal to noise ratio (Feher 1957).

The mechanical performance depends upon the absence of backlash in the two small gears. These each have eleven teeth cut by 0.7 mm and 0.6 mm slitting saws. Measurements showed that a reproducibility of about 2° is readily achieved in rotation about the horizontal axis, which may be improved if the rotation is always performed in the same direction. Rotation about the vertical axis is performed with much greater precision.

The mounting lacks cylindrical symmetry and causes some detuning of the cavity when turned about a vertical axis. The effect is sufficiently small that a minor and momentary adjustment of either klystron reflector voltage or nylon tuning stub inside the cavity is sufficient after each new setting.

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Diode leak-detector control unit

by D. ALLENDEEN, A.M.I.E.E., Associated Electrical Industries Ltd., Research Laboratory, Aldermaston, Berks.

MS. received 30th June 1961

The emission current of a temperature-limited diode is reduced in the presence of weak oxygen concentration and the device can hence be used as a leak detector in the manner described by Bloomer and Brooks (1960). This note describes a comprehensive control unit for the A.E.I. type V1984 leak detector diode which provides the following facilities:

(a) stabilized d.c. filament current in the range 0.5 to approximately 2.5 A; (b) stabilized +140 v anode voltage; (c) direct meter indication of fractional reduction of emission ($\delta I_e/I_e$); (d) controlled 'flashing' of the diode filament at 2.8 A for 10 seconds for conditioning purposes.

The fractional change in anode current varies with its magnitude. In the range from approximately 500 μ A to 5 mA an emission decrease of up to 20% is typical, whilst at currents below 500 μ A smaller leaks can be detected with changes of emission which may approach 100%. In operation the desired emission current is first established by adjustment of filament power, and setting the measuring amplifier to zero. Thereafter a decrease of 20% (or 100%) in this current produces full-scale deflection on the meter.

A circuit of the unit is given in Fig. 1. Filament power is provided by a low-voltage transistor-stabilized supply using full-wave rectification and a large reservoir capacitor. The stabilizer employs cascaded emitter followers Q_1 , Q_2 , in a

series regulator circuit with a single-stage grounded-emitter error amplifier Q_3 . A single electrolytic stabilizer (A-E) cell in Q_3 emitter circuit provides reference voltage. Voltage rather than current stabilization is employed, since it gives rather higher loop gain for the same circuit elements. The sampling divider R_1 , RV_1 , R_2 is fed by pilot leads to include the filament supply leads in the feedback loop.

The voltage control is graded by a fixed resistor R_3 connected across it to obtain a more linear variation of emission.

The filament can be flashed by operation of S_3 , which energizes relay A_4 for a period of approximately 10 seconds timed by delay switch V_2 . Contacts A_4 short-circuit the control transistors and apply full power to the filament whilst A_3 disconnects the measuring amplifier input during flashing. The circuit gives first-order compensation against mains changes, since an increase of filament voltage is largely offset by the shorter delay time of the thermal switch.

The two ranges of the measuring amplifier are:

- (1) 5 mA–500 μ A emission, meter full-scale deflection = 20% decrease in emission.
- (2) 500 μ A–5 μ A emission, meter full-scale deflection = 100% decrease in emission.

The detector diode anode voltage is provided by a 150 v neon-stabilized supply. The diode emission current flows

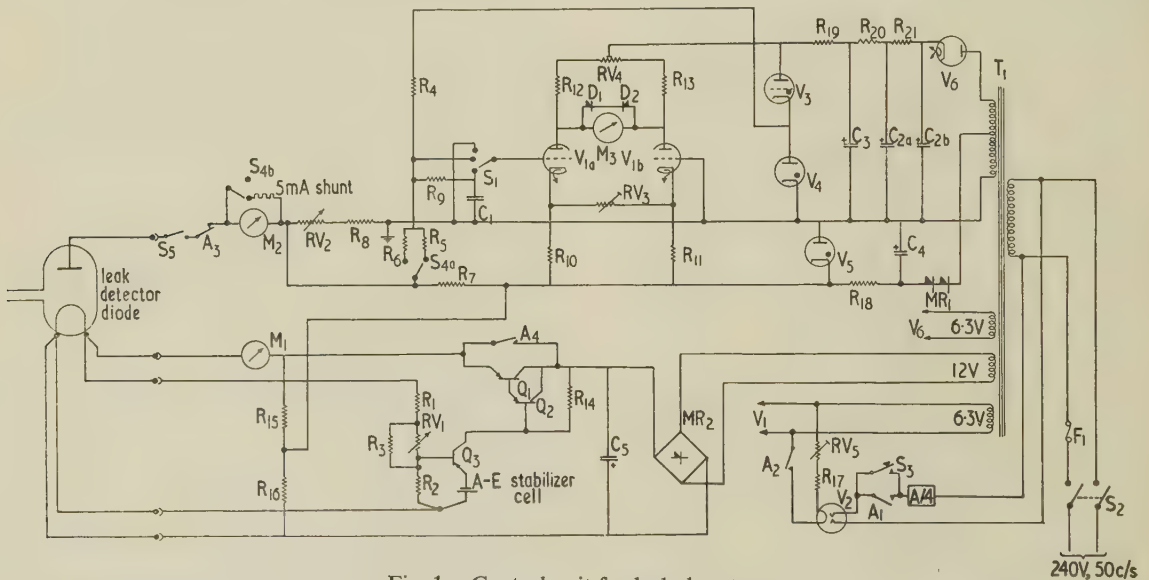


Fig. 1. Control unit for leak detector.

$R_1 = 33 \Omega$ w.w.
 $R_2, R_3 = 100 \Omega$ w.w.
 $R_4 = 3.3 \text{ M}\Omega$, h.s. $\pm 5\%$
 $R_5 = 330 \text{ k}\Omega$, h.s. $\pm 5\%$
 $R_6 = 68 \text{ k}\Omega$, h.s. $\pm 5\%$
 $R_7 = 3.3 \text{ M}\Omega$, h.s. $\pm 5\%$
 $R_8 = 2 \text{ k}\Omega$ w.w.
 $R_9 = 2.2 \text{ M}\Omega$
 $R_{10}, R_{11} = 33 \text{ k}\Omega$
 $R_{12}, R_{13} = 10 \text{ k}\Omega$
 $R_{14} = 2.2 \text{ k}\Omega$
 $R_{15}, R_{16} = 100 \Omega$
 $R_{17} = 5 \Omega$ w.w.
 $R_{18} = 1.5 \text{ k}\Omega$ w.w.
 $R_{19}-R_{21} = 2.2 \text{ k}\Omega$ w.w.

Resistors $\frac{1}{2}$ w, 10% tolerance, except where otherwise stated.

$RV_1 = 500 \Omega$ w.w. set emission
 $RV_2 = 20 \text{ k}\Omega$ w.w. balance
 $RV_3 = 1 \text{ k}\Omega$ preset, calibrate
 $RV_4 = 5 \text{ k}\Omega$ w.w. set, amplifier zero
 $RV_5 = 10 \Omega$ w.w. set, flash period

$C_1 = 0.5 \mu\text{F}$, 200 v, paper
 $C_{2a-b} = 8 + 16 \mu\text{F}$, 550 v, electrolytic
 $C_3, C_4 = 32 \mu\text{F}$, 350 v, electrolytic
 $C_5 = 5000 \mu\text{F}$, 15 v, electrolytic

$D_1, D_2 = \text{VR625A}$, Zener diodes

$F_1 = 1 \text{ A}$ fuse

$MR_1 = 2 \times \text{GJ5M}$
 $MR_2 = 4 \times \text{GEX541}$

$M_1 = 3 \text{ A}$, filament current
 $M_2 = 500 \mu\text{A}$, emission
 $M_3 = 6 \text{ v}$, f.s.d. 1000 Ω/v

$V_{1a-b} = 12\text{AU7}$
 $V_2 = \text{Mazda ST14}$ delay switch
 $V_3-V_5 = \text{CV1833}$, 108C1
 $V_6 = \text{CV2218}$, R17

T_1 secondaries:
 150–150 v 40 mA
 6.3 v 1 A
 6.3 v 1 A
 12 v 3 A

$Q_1 = 2 \times \text{XC142}$ in parallel
 $Q_2 = \text{XC142}$
 $Q_3 = \text{XB121}$

rough a variable measuring resistor in the anode circuit, chosen that the voltage drop across it is 10.5 v (on the mA range). This voltage is backed off by resistor chain R_5 , R_6 , and the difference voltage applied to a simple diode-coupled amplifier V_{1a-b} , the sensitivity of which is adjusted to give full-scale deflection for 2.1 v input. On the 'w' range the measuring resistor drop is reduced to 2.1 v and the divider ratio changed so that full-scale deflection now corresponds to a 100% decrease.

Resistor R_7 eliminates errors due to the divider current passing through the measuring resistor. An emission milliammeter is provided and has its range changed automatically by S_{4a} .

Switch S_1 has three positions:

(a) the amplifier zero set; (b) normal operation; and (c) a one-second smoothing time-constant, inserted for use in 'noisy' systems. The smoothing capacitor C_1 is so connected as to be permanently charged to the appropriate voltage, and there is thus no transient when it is switched in. Overload protection is provided by Zener diodes across the meter.

Power supplies are conventional, the low current drain allowing half-wave rectifiers and R-C filters to be employed with gas-tube stabilization.

Under operating conditions the emission stability is within 1% over several hours. Short-term performance is significantly better, being typically less than 1% over 15 minutes. Figure 2 shows a stability record taken under these conditions in a sealed-off glass system.

The author is indebted to R. N. Bloomer and W. C. Brooks, who developed the diode, for many helpful discussions, and to Dr. T. E. Allibone, Director of the Laboratory, for permission to publish this note.

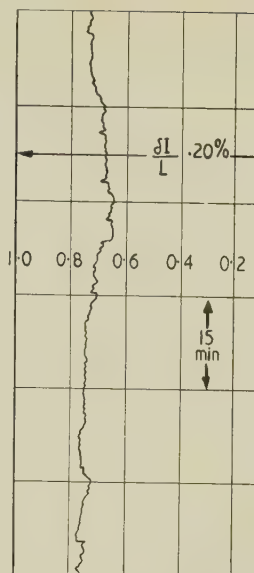


Fig. 2. Stability record.

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Stability of the e.m.f. of cells under continuous low-drain conditions

J. GODDARD,* Light Division, National Physical Laboratory, Teddington, Middlesex

(S. received 15th August 1961, in revised form 13th September 1961)

The standard cell is the usual laboratory reference source of a very stable e.m.f. but for some less critical applications a dry cell or accumulator may be sufficiently stable and these have the advantage that current may be drawn from them. The literature gives very little information about the stability to be expected so it was decided to test three types of cell: an air depolarized cell (ADS2, B.S. 1335), a Leclanché cell (L.40, B.S. 397) and a 30 ampere-hour lead acid accumulator. The cells were allowed to discharge through a 10 kΩ resistor, since this was the input resistance of a Varley potential divider with which they were to be used to provide the 'backing-off' voltage for a precision photoelectric photometer. The properties investigated were overall drift of e.m.f., temperature coefficient and random changes in e.m.f. Voltages were measured to $\pm 10 \mu\text{V}$ with a vernier potentiometer. The temperature of the cells was measured by mercury glass thermometers which were strapped to the outside casing. Constant temperature enclosures steady to $\pm 0.25 \text{ deg C}$ were used in some of the tests.

* Sandwich course student from Brunel College of Technology.

Drift

The cells were left discharging for several weeks in a room which was subject to temperature changes of approximately $\pm 2 \text{ deg C}$ about a mean of 18°C . A typical result for the ADS 2 is shown in Fig. 1. The values found for mean downwards drift rate were:

ADS	0.6 parts in 10^5 per hour
Leclanché	2.3-5 parts in 10^5 per hour
Accumulator	1.7 parts in 10^5 per hour.

Temperature coefficient

In a preliminary experiment the cells were placed inside a metal container with two inches of cork insulation all round. It was found that the temperature fluctuations in the box were still about half the size of those occurring in the room. A greater advantage may have been the reduction in rate of change of temperature of the cell, since this factor is also important.

No consistent results were obtained from an attempt to

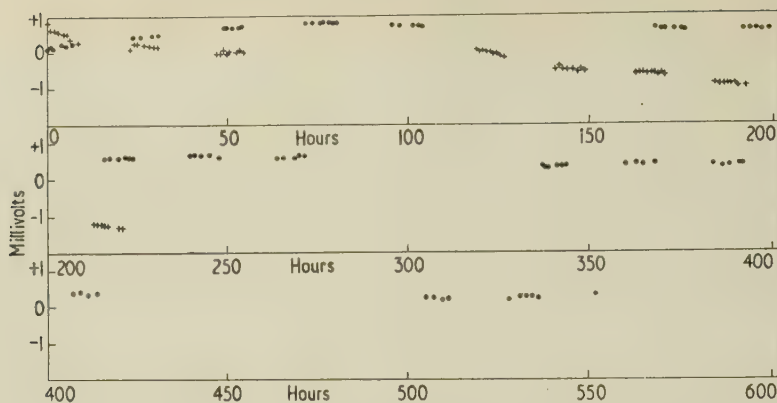


Fig. 1. Comparison of drift of voltage across 10 kΩ load obtained with

- +++++ ADS 2 dry cell at room temperature, $18 \pm 2^\circ \text{C}$, $V_{t=0} = 1.409 \text{ v}$.
 Leclanché 'no drift' circuit in thermostatically controlled box $25 \pm 0.25^\circ \text{C}$, $V_{t=0} = 1.545 \text{ v}$.

deduce the individual dry cell temperature coefficients from measurements of temperature and e.m.f. made when the cells were discharging through 10 kΩ in the room. For the accumulator a value of $+0.0003 \text{ v/deg c}$ was obtained and

for the Leclanché cells used in a drift-compensated circuit the approximate value was also $+0.0003 \text{ v/deg c}$.

In another experiment single cells discharging through 10 kΩ were taken from the room at 20°C and placed in enclosures at 0°C and at 40°C . Typical results are shown in Fig. 2 and Fig. 3. The small pip in the first few minutes is apparently connected with the initial temperature gradient across the electrolyte of the dry cells. From the ensuing behaviour it is clear that the effective temperature coefficient of e.m.f. of a cell will depend critically upon the way in which the temperature is changed. Although consistent results may be obtained by changing the temperature of the cell gradually by small amounts and then waiting for a considerable time for equilibrium to be attained, these results will not be of very general application. For cells exposed to continual changes in temperature the value $+0.0003 \text{ v/deg c}$ may be taken as a guide.

Random changes

If one measures the e.m.f. of a dry cell at the start of a given period and corrects for drift rate and temperature to obtain subsequent values of e.m.f. there will be a remaining uncertainty due to the inexactness of the corrections and changes in the chemical behaviour of the cell. The magnitude of this uncertainty is estimated at $\pm 0.0002 \text{ v}$ during any individual day, when the cell is subject to changes in temperature of the order $\pm 2^\circ \text{C}$. It is an order of magnitude smaller if the temperature is kept constant.

All the results described in this paper were obtained with previously unused cells and a new, freshly charged accumulator. A two-year-old ADS cell, which had been used intermittently to supply fairly high currents, displayed the same qualitative behaviour as a new cell but was less stable. Measurements made with dry cells on open circuit gave similar results to those obtained using 10 kΩ loads, except that the overall drift was less predictable.

Drift compensation

In an attempt to reduce the effects of drift the circuit shown in Fig. 4 was used both with Leclanché and ADS cells. The resistor R was adjusted until the drift rate of the single cell was equal to the combined drift of the two opposing cells, thus the voltage across the 10 kΩ load was substantially constant. In this test the cells were kept in a constant

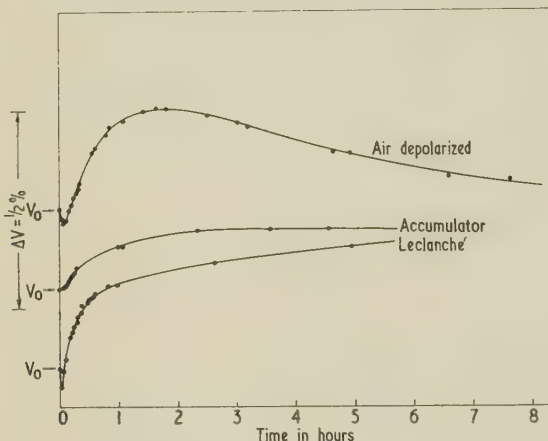


Fig. 2. Typical curves showing fractional change in voltage across 10 kΩ load as a function of time. Ambient temperature was changed from 20°C to 40°C at $t = 0$.

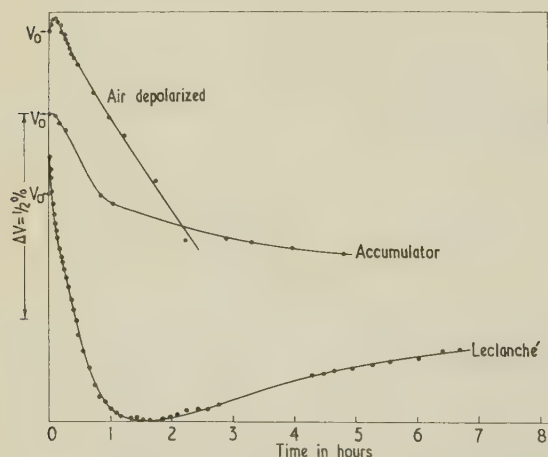


Fig. 3. Typical curves showing fractional change in voltage across 10 kΩ load as a function of time. Ambient temperature was changed from 20°C to 0°C at $t = 0$.

temperature enclosure and measurements were made during period of about a month. The Leclanché cells gave the best performance because they settled down to a steady

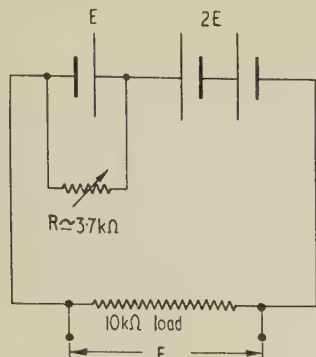


Fig. 4. Diagram of 'no drift' circuit. R was adjusted until the drift in load voltage was minimized.

drift rate more quickly, making the initial setting of the resistor R easier. This result is shown in Fig. 1. During the entire test period the voltage across the load remained between 1.545 and 1.546 v and on individual days was

Temperature rise in a barrier-layer photocell exposed to sunlight

by D. PAIX, M.Sc., Grad.Inst.P., Commonwealth Experimental Building Station, Sydney, Australia

(MS. received 6th June 1961, in revised form 24th July 1961)

The suitability of selenium barrier-layer photocells for exposure out of doors has been discussed by several authors (Foster 1951, Drummond 1956), but little information appears to be available on the temperatures likely to prevail in cells so exposed. This information is required because the output in many cases is temperature-dependent, and because 140° F is generally quoted as the maximum temperature which such cells can tolerate without damage. Some temperature data obtained from a Western type 856 YGVW cell exposed to the sunlight during a summer at Sydney, Australia, are presented in this note.

Data collected in the course of building research indicate that roof surfaces exposed to sunlight can exceed 150° F, the actual value being dependent upon the wind velocity, the air temperature, and the characteristics of the surface. An estimate based on Billington's (1952) discussion of these matters gives an even higher value. Thus it appears quite likely that damage from overheating would occur in a fully exposed photocell.

The experimental data showed that damage did not in fact occur, and that the maximum permissible temperature was not quite reached. It did not, however, give an assurance that overheating would not occur under different circumstances. A cosine corrector of the design recently described (Weston and Paix 1960) was attached to the cell and fully exposed to the sun and sky with the receiving surface horizontal. The brass part of the upper surface was matt black.* A thermocouple had been passed through the cell's weather-proof housing and attached to the case of the photocell

* A brief test indicated that on a clear summer day painting the brass white reduced the cell temperature about 5 deg F.

constant to ± 2 parts in 10^5 . With such low currents the life of the dry cells should be of order three years: it would presumably be necessary to readjust R occasionally to maintain optimum performance.

Conclusion

During a week the stability of e.m.f. of the three types of cell when exposed to room conditions is seen to be of the order $\pm 0.1\%$ if no corrections are made for temperature changes and drift.

Using Leclanché cells the drift may be greatly reduced by the technique described, giving a stability of $\pm 0.05\%$ during a month or $\pm 0.002\%$ during a day.

The effective temperature coefficient of voltage for the three types of cell in normal laboratory conditions was found to be $+0.0003$ v/deg C.

Acknowledgment

The work described above was carried out as part of the research programme of the National Physical Laboratory under the supervision of Dr. O. C. Jones. This paper is published by permission of the Director of the Laboratory.

proper. Radiation striking the photosensitive surface had first to pass through 0.21 in. of grade 040 opal Perspex, and a 'Viscor' colour-correcting filter.

The maximum temperature observed was 136° F, on a day of 104° F air temperature and wind velocity 8 m.p.h. During the period of temperature measurements, from 5th January to 11th February 1961, the cell temperature exceeded 120, 125, and 130° F for 12, 7½ and 2¼ hours respectively. Calibrations against a standard lamp revealed no alteration in the sensitivity of the cell (subject to an accuracy to $\pm 2\%$ in the calibration procedure).

The highest temperature observed was very close to the permissible value, and there is no assurance that overheating would not occur on hot, calm days, for the temperature rise to be expected rises rapidly as the wind velocity approaches zero. The likelihood of overheating could be assessed at a particular place from weather records as the likelihood of experiencing a clear day, with a temperature of 105° F and a wind velocity less than 8 m.p.h.

The work described in this note was undertaken as part of the research programme of the Commonwealth Experimental Building Station; the note is published by permission of the Director, Commonwealth Experimental Building Station, and Crown copyright is reserved.

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Isotopic discrimination introduced by electron multiplier detectors in mass spectrometry

by B. L. CAMPBELL A.S.T.C., and R. N. WHITEM B.Sc., Australian Atomic Energy Commission, Sydney, N.S.W., Australia

MS. received 11th September 1961

Electron multiplier detectors are frequently employed in surface ionization mass spectrometers used for precise isotope abundance ratio measurements. Several authors have pointed out that discriminations arise from this form of detector, and this topic was reviewed recently by Akishin (1958).

The most commonly used correction is that based on the assumption that ions of equal velocity produce the same number of secondary electrons at the target of the multiplier. Since all ions have the same kinetic energy, this correction takes the form:

$$\left(\frac{a}{b}\right)_{\text{real}} = \left(\frac{a}{b}\right)_{\text{measured}} \left(\frac{m_b}{m_a}\right)^{-\frac{1}{2}}$$

Palmer (1959) has doubted the precise validity of this correction factor, finding 10% discrimination for $^6\text{Li}/^7\text{Li}$ instead of the predicted 8%.

Ploch and Walcher (1953) have proposed a semi-empirical correction factor of the form

$$\left(\frac{a}{b}\right)_{\text{real}} = \left(\frac{a}{b}\right)_{\text{measured}} \left(1 + q \cdot \frac{\Delta m}{m}\right)$$

where q is an empirical factor $\frac{di}{i} \frac{dU}{U}$ determined by noting the change in multiplier current when the accelerating voltage is varied from U to $U + dU$. (U is the sum of the accelerating voltages in source and detector, but only the source voltage is varied.)

Using a Metropolitan-Vickers mass spectrometer type MS5, which is a 90° sector instrument of 12 in. radius, employing

an 11-stage Be-Cu multiplier, we have measured the multiplier discrimination in two cases, $^{235}\text{U}/^{238}\text{U}$ and $^{84}\text{Sr}/^{88}\text{Sr}$.

These factors were determined by comparing ion ratios obtained using multiplier detection and conventional plate detection. So that amplifier non-linearities, range factors, etc., would not influence the result, synthetic samples having approximately unit ratio of the selected isotopes were used.

The results are shown below, the limits quoted being 95% confidence levels.

	Discrimination factor	
	$^{235}/^{238}$ uranium	$^{84}/^{88}$ strontium
This work	1.0088 ± 0.0018	1.0289 ± 0.0043
Simple velocity correction	1.0064	1.0234
Ploch and Walcher correction	1.0126 ± 0.0010	—

These results show a significant deviation from the simple velocity correction, and are in line with those obtained by Palmer (1959) for lithium.

The Ploch and Walcher correction does not apply in our case. This may be due to a discrimination in the ion source caused by varying the accelerating potential.

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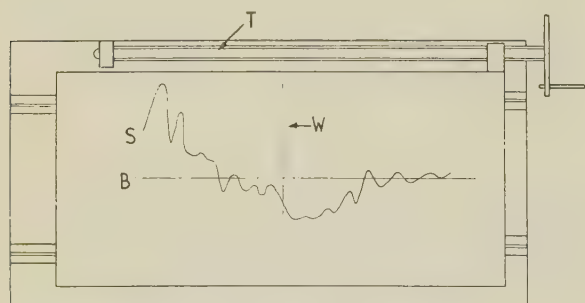
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Simple device for digitalizing oscilloscope recordings on to punched tape

by I. M. FRENCH, Research Laboratory, Associated Electrical Industries Ltd., Aldermaston, Berks.

MS. received 21st August 1961

For auto and cross correlation by electronic computer of fluctuating signals which are photographically recorded on a multichannel oscilloscope, the waveforms must be converted



into a digital form. The computer is programmed to apply a correction, from a time calibration, for non-linearity of time base and for differences in gain between individual traces.

The trace reader consists of a movable stage moving on steel balls in two V grooves and on to which the traces are projected optically. The stage is moved along by means of an 0 B.A. screw thread T by 1 mm per revolution. A potentiometer wire W runs across the middle of the stage at right angles to the direction of travel of the stage. The slider contact consists of a wire stretched across a flat piece of Perspex. The potential is read on a digital voltmeter giving 3 decimal digits. The digital voltmeter is controlled so that on pressing a foot-switch it automatically resets, reads the voltage and then prints out the result on to a teleprinter which also produces the data tape required by the computer. The

potential across the wire is provided by an accumulator via a variable resistor and is set to approximately 1 v or a reading of 999 on the digital voltmeter.

The trace is projected on to the trace reader with its base line parallel to the direction of travel of the stage. The potentiometer wire is aligned with the start of the base line B and a reading RB taken at the point of intersection of the base line and the wire. A reading is then taken at the intersection of the wire and the start of the waveform S; the stage is then moved along 1 mm by one turn of the handle and a new reading taken.

The computer subtracts the first reading, RB (about 500), from all subsequent readings, to give readings with a possible range of -500 to $+500$ and taken at 1 mm intervals along the trace. It then applies time and amplitude corrections and stores the information for subsequent analyses.

Acknowledgments are due to Mr. P. Redman who programmed the Pegasus computer, and Dr. T. E. Allibone, Director of the Laboratory, for permission to publish this note. Part of the work was done under contract to the Atomic Energy Research Establishment.

NOTES AND NEWS

New instruments, materials and tools

The Editor invites manufacturers of instruments and light machine tools to keep her informed of their new or improved products. The Institute of Physics and The Physical Society assumes no responsibility for the statements given below; information for these has been taken from literature supplied.

Wide-range R-C oscillator. Marconi Instruments Ltd., St. Albans, Hertfordshire.

The type T.F. 1370 is a Wien bridge oscillator covering the range 10 c/s to 10 Mc/s (sinewave) in six decade bands. A single scale is used for the four lower bands and separate scales for the two upper bands; this gives a total scale length of 105 in. and makes a 1% change in frequency easily discernible. There is a dual-ratio control of tuning having 3 : 1 or rapid adjustment and 18 : 1 for fine tuning.

Outputs from 1 mv to 3·16 v are available via a switched attenuator covering 60 db in ten-decibel steps. The signal level applied to the input of the attenuator is continuously variable and is monitored by a meter calibrated in open-circuit voltage and decibels.

The output impedance can be set to 75, 100 or 600 ohms. Low outputs down to 10 μ v at 75 or 5 ohms can be obtained by means of an $\times 100$ attenuator pad available as an optional extra. High outputs up to 31·6 v at frequencies below 100 kc/s are delivered at a separate outlet.

The T.F. 1370 also delivers squarewave outputs up to 31·6 v peak at frequencies between 10 c/s and 100 kc/s.

Wide-band millivoltmeter. Marconi Instruments Ltd., St. Albans, Hertfordshire.

The type T.F. 1371 millivoltmeter has a frequency cover of 10 c/s to 30 Mc/s with a voltage range from 100 μ v to 300 mv or up to 30 v with an optional multiplier. The instrument has a 5½ in. meter which responds to the average value of an a.c. waveform and is calibrated in the r.m.s. value of a sine-wave; it has two millivolt scales, and a scale showing decibels

relative to 1 mw in 600 ohms. To maintain long-term accuracy the calibration can be easily standardized against an internal source.

Electrocymograph. VEB Carl Zeiss JENA, Jena, Carl-Zeiss-Strasse 1.

The electrocymograph has been developed for recording the movements of the heart wall, of large blood vessels or volume pulsations of the lung. These movements are detected by a photomultiplier as small light fluctuations of a precisely defined area of an x-ray screen. A unit containing the photomultiplier is fixed by straps to the screen of a normal x-ray plant, a lead slit being positioned and orientated appropriately to define the area to be examined. Cables pass from the unit to the operating console which can be positioned outside the x-ray room. A two-channel electrocardiograph mounted on top is used to record the electrocymogram in conjunction with a normal electrocardiogram.

Surgical microscope II and colposcope III. VEB Carl Zeiss JENA, Jena, Carl-Zeiss-Strasse 1.

These two instruments have the same optical unit consisting of a binocular microscope and an illuminating system. The microscope can be used at magnifications of 5, 8, 12·5, 20 and 32 $\times$ as required and either a red or a daylight filter can be moved into the optical path. The microscope has drives for precision setting of movement in the direction of the optic axis and of tilt. Adequate illumination of the object is achieved using a 6 v 15 w lamp in an entirely separate optical system so ensuring no loss of contrast. A camera attachment is provided having a magnification of 1·25, giving an image size of 24 mm by 36 mm. This is operated with a xenon flash brought in optically in place of the normal illumination by a movable mirror at the moment of exposure. The surgical microscope is mounted on a fully articulated arm fixed to a counterbalanced carriage which moves on ball bearings on a substantial vertical pillar. The vertical move-

ment of the colposcope is achieved by a counterbalanced parallelogram linkage with a rigidly constructed jointed arm for coarse adjustment both laterally and in depth.

Sharples polariscope (for photo-elastic stress analysis.)

Sharples Engineering Co. (Bamber Bridge) Ltd., Chorley Road, Walton-le-Dale, Preston, Lancashire.

The Sharples polariscope is unique in that provision is made for using it either as a diffused light or as a transmission instrument. When used as a diffused light instrument the light sources are a 60 w sodium vapour lamp for monochromatic light and two 150 w tungsten filament lamps for white light illumination. When used as a transmission system the housing for the above lamps is replaced by a platform which carries a 250 w tungsten filament lamp and a condenser lens.

The 5½ in. diameter polaroid disks and quarter wave plates can be rotated separately through 360°, their rotation being read off scales fixed to their housings. Model loading is normally through a lever and dead weight system. Tensile, compressive, flexural and torsional loads can all be applied. The models may be moved vertically, sideways and may also be swivelled to adjust for space effect. The complete instrument is mounted on its own cabinet in which there is ample storage space for models and loading equipment, etc.

Zone-refined tellurium and gallium arsenide. Johnson, Matthey and Co. Ltd., 73-83 Hatton Garden, London, E.C.1.

Zone-refined tellurium. The total metallic impurity content, excluding selenium, is less than 5 parts per million and is normally in the region of 1 part per million. The selenium content does not exceed 5 parts per million. The tellurium is supplied in the form of half-round bars, approximately 1 in. $\times$ ½ in.

Gallium arsenide. Sample quantities of this compound are now available in polycrystalline form. A single-crystal material should be available shortly. Typical properties of polycrystalline gallium arsenide are: resistivity 0.01-0.2 Ω cm, Hall coefficient 50-250 cm³/C, electron mobility 2000-4000 cm²/vs, carrier concentration 1-30 $\times 10^{16}$ /cm³. The material is available either as broken ingot or cut slices.

Rocol molytherm grease. Rocol Ltd., Rocol House, Swillington, nr. Leeds.

This grease, which is designed specially to provide lubrication for machinery at high temperatures, will withstand continuous running at 350° F, long periods at 450° F and short periods up to 550° F.

The grease is based on a high flash point oil and a non-soap thickener which is unaffected by heat or chemicals. It is resistant to steam and water, and shows considerable resistance to the stripping action of solvents and vapours. Tests have been carried out which show the superior heat stability of Rocol molytherm grease to lithium and bentonite greases.

Reciprotor. Edwards High Vacuum Ltd., Manor Royal, Crawley, Sussex.

The Reciprotor is a combined vacuum/pressure pump manufactured in Denmark, and consists of two opposing pistons on a common shaft which is vibrated at mains frequency by a coil and armature, the armature being a permanent magnet fixed to the piston shaft. The pistons have nylon rings and work in polished steel cylinders. No lubrication is required and thus completely oil free air delivery is obtained. Piston

rings have a life of 2000-4000 hours. There are two versions of the Reciprotor—the type 406G for continuous operation with a free air displacement of 1.62 ft³/min, a vacuum of 18 in. Hg and a maximum pressure of 7.8 lb/in², and the type 606G for intermittent operation with a displacement of 1.77 ft³/min, a vacuum of 22 in. Hg and a pressure of 10.7 lb/in².

Pressure transducer. Consolidated Electrodynamics Corporation, 360 Sierra Madre Villa, Pasadena, California, U.S.A.

The type 4-329 pressure transducer incorporates the unbonded strain gauge principle, a spring-type sensing element with four active arms and a diaphragm force-summing area. The sensing element is in a sealed case surrounded by an aluminium housing. The type 4-329 is a chamber-type unit designed for absolute measurement of fluids compatible with aluminium and type 416 with stainless steel.

Pressure ranges are 0-100, 250, 500, 1000, 1500, 2500, 3500 and 5000 lb/in² absolute and an over pressure of 1.5 times rated range will not damage the transducer. Electrical excitation is 20 v d.c. or a.c. r.m.s., 0-20 kc/s input impedance 700 Ω minimum. Output sensitivity is 50 mv $\pm$ 0.25 mv into a 50 k Ω load at rated excitation and 77° F. Linearity and hysteresis is $\pm$ 0.35% of full range. Natural frequency is approximately 25 kc/s for 100 lb/in² transducer, increasing logarithmically with pressure to 50 kc/s for 5000 lb/in² transducer. Output impedance is 350 $\pm$ 10% at 77° F, repeatability $\pm$ 0.1% of full range output.

D.C. amplifier. Packard Bell Computer Corporation, 190 S. Armacost Avenue, Los Angeles 25, California, U.S.A.

The Redcor model 500 is a single ended wide band d.c. amplifier for instrumentation applications. The gain is adjustable from 10 to 1000 and the bandwidth adjustable from 10 c/s to 100 kc/s. The input impedance is greater than 1000 M Ω and the output can give $\pm$ 10 v at 100 ma.

The model 500 contains two single ended amplifiers in one package using a common power supply. This is an all solid state design with choice of gain and bandwidth characteristics by plug-in input modules. A low cost version model 500A is available with integral input circuits controlling gain and bandwidth.

Regulated power supply for high power semiconductor work. Hewlett Packard Co., 1501 Page Mill Road, Palo Alto, California, U.S.A.

The model 722 AR regulated power supply provides up to 2 A at 0-60 v d.c. For safety to load, maximum current can be set anywhere between 100 ma and 2.2 A. Remote sensing allows regulation at the load to be applied thus compensating for the effect of hook-up leads.

Performance: line regulation less than 2.5 mv change for $\pm$ 10% line voltage change; load regulation less than 5 mv change for 0-2 A change output set between 0-60 v; noise and ripple less than 250 μ A r.m.s.; temperature stability better than 0.02% per deg C; temperature range 0 to 55° C for operation within specifications; output impedance d.c., less than 2.5 m Ω a.c., less than 5 m Ω in series with 10 μ H. The unit has forced air cooling and requires 115/230 v $\pm$ 10%, 50 to 60 c/s, 300 w max.

Photoconductive cell type ORP 13. Mullard Ltd., Tarrington Place, London, W.C.1.

The ORP 13 is intended for applications involving infra-red spectroscopy and research into the properties of materials.

has a sensitive area of approximately 3 mm² of indium antimonide and is attached to its own Dewar flask by which is cooled with liquid nitrogen to a temperature of 77° K. The cooling system enables good noise figures to be obtained and allows the cell to be used for 45 minutes per filling. The spectral range is from visible to about 5400 mμ, the peak occurring between 4500 and 5400 mμ and giving a sensitivity of monochromatic radiation of 15 mv/μw of incident radiation.

Photomultiplier tube type 58 AVP. Mullard Ltd., Torrington Place, London, W.C.1.

The latest addition to the Mullard range of photomultipliers is a 14-stage tube suitable for use with gas scintillators and for detecting Cerenkov radiation. It has a tetrode input system and achieves very short transit times. The photocathode has a useful diameter of 110 mm and an average sensitivity of 50 μA/lm, while its peak spectral response occurs at 420 mμ. Average anode sensitivity is greater than 1000 A/lm, current amplification exceeds 10⁸, and maximum dark current is 10⁻¹⁵ A at minimum anode sensitivity.

Silicon photovoltaic cell, type BPY 10. Mullard Ltd., Torrington Place, London, W.C.1.

The BPY 10 is intended primarily for use in multi-track punched card and punched tape read-out systems, special features appropriate to this application being its virtual immunity to vibration and its small size, 0.088 in. × 0.086 in. × 0.25 in. The cell has a spectral response with a range of 90–1100 mμ and a peak response at 900 mμ. It has an average sensitivity of 4 mA/lm and is usable over a temperature range of -65° C to +70° C. Connections are by wire leads.

'Microtact' relay. Leland Leroux Ltd., 145 Grosvenor Road, London, S.W.1.

This moving coil measuring relay is a smaller sealed version of the well-known 'Sensitact' relay. It comprises a screened moving coil galvanometer movement in which a moving contact engages with fixed contacts at either end of the arc of travel. Alternative windings of 2500, 125 and 2.5 ohms give full scale sensitivities of 50, 250 and 2500 μA respectively, each case relays being obtainable in which, with no current flowing, the moving contact rests either against the fixed 'minimum' contact or centrally between the latter and the 'maximum' contact, although contacts can be set before assembling to meet special requirements. The precise operating currents can be adjusted electrically over a wide range by means of a suitable external potentiometer available as an extra. Response time is 0.1 to 0.5 second according to the model and to the positions at which the contacts are set, and operating tolerance is ± 1.5% of full scale current. Overall

dimensions are 40 mm long and 20 mm diameter, and weight is about 1.12 oz. Contact power handling capacity is 30 mw at a maximum of 20 v a.c. or d.c.

Portable double beam oscilloscope, type CT 436. Solartron Laboratory Instruments Ltd., Cox Lane, Chessington, Surrey.

The CT 436 is a portable double-beam oscilloscope which operates either from 45–400 c/s a.c. mains or 24/30 v d.c. and weighs 28 lb. It has two separate Y channels (DC–6 Mc/s), with independent controls. Y₁ and Y₂ amplifier sensitivities of 100 mv/cm to 100 v/cm are covered in 10 ranges (switched in 1–2–5 sequence) with accuracy to ± 5%, while an additional 10 × gain gives a maximum sensitivity of 10 mv/cm (3 c/s–500 kc/s). Continuous coverage is provided by a fine gain control. 0.4 μs signal delay (on both channels) permits leading edges of fast pulses to be examined. Two diameters of Y shift are provided and the Y plates are accessible. The 1 cm/μs to 2 cm/s time-base, covered in 18 calibrated ranges (switched 1–2–5 sequence), may be used in the repetitive, triggered, or auto-triggered modes. A fine control, with a calibration position, provides continuous coverage. The measuring accuracy is to ± 5%. 'Level' and 'stability' controls enable the sweep to be triggered from any selected point on the triggering wave-form. The time-base wave-form is available at output sockets (app. 15 v pk-pk via cathode follower, 150 v pk-pk at high impedance for driving sweep generators). X-shift enables either end of the trace to be centred at all settings of X gain control. External signals may be applied to the X-amplifier (DC–500 kc/s), input impedance 1 MΩ/30 pF. Sensitivity is continuously variable from approx. 0.2 v/cm to 2 v/cm. A 1 kc/s square wave of 0.5 v pk-pk ± 1% is available for calibration, and a similar waveform is available at 7.5 v for setting probes. The stabilized E.H.T. (1.75 kv) ensures that calibration is independent of brightness levels. External brightness modulation facilities are provided, 5 volts pk-pk applied to the grid of the cathode-ray tube giving full modulation. The edge illuminated graticule is calibrated in centimetres with 2 mm subdivisions.

Corrigendum

Vacuum gas analyser. Wild-Barfield N.R.C. Model 912.

J. Sci. Instrum., **11**, 454.

We regret that two incorrect statements were included in the review of the above instrument. These should be:

Lines 7–8. 'The machine consists of three main parts, a furnace, a *pumping system* and an analytical system.'

The pumping system is not merely a diffusion pump, as stated.

Lines 18–21. 'The resultant mixture of carbon monoxide, hydrogen and nitrogen is pumped out by a transfer pump and drawn into a McLeod gauge by a Toepler pump.'

Notes and comments

Notes for the Preparation of Papers for the *Journal of Scientific Instruments*

The following instructions refer to the main points which have to be considered in the preparation of a paper for publication, and authors offering papers to the *Journal of Scientific Instruments* for publication are asked to conform to these recommendations.

Manuscripts

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- Notes and comments. New Books.

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